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Title: Waste Campaign 303 - Installation of PRDw SF on RNS Waste Containers

at LANL

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# Waste Campaign 303 - Installation of PRDwSF on RNS Waste Containers at LANL

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# **REVISION HISTORY**

Document No. /Revision No.	Issue Date	Action	Description
WC-303, R.0	April 28, 2016	New Document	Initial release of waste campaign plan for the installation of additional pressure relief device with supplemental filtration (PRDwSF) capability to each remediated nitrate salt (RNS)-bearing waste container.
WC-303, R.1	December 8, 2016	Major Revision	Revision to comply with ESS R6.1 to include corrective actions related to RNS waste packaged in pipe overpack containers (POCs) which were not covered by the supplemental venting actions specified in ESS R.5.

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Note: For simplicity in development of this revision, the use of future tense descriptions for installation of the pressure relief device with supplemental filtration (PRDwSF) on standard 55-gallon drums were not changed to past tense even though installation was completed in May 2016.

#### 1. WASTE CAMPAIGN BACKGROUND

Waste Campaign (WC) 303 consists of 48 55-gallon drums and eight pipe overpack containers (POCs) remediated nitrate salt (RNS) daughter containers. There are a total of 60 RNS waste containers; however, this waste campaign plan will only address the 48 standard 55-gallon containers, and eight POCs in standard waste boxes (SWBs). The four POCs overpacked in 85gallon drums are not included in this waste campaign. Full-scale container tests performed by Los Alamos National Laboratory (LANL) have determined that the potential for a sustained thermal runaway reaction in a container of RNS waste is more likely to occur if the container is pressurized and/or at elevated temperatures. Filter vent blockage or overwhelming gas flow may compromise the filter vent and result in drum pressurization. WC 303 addresses the installation of a PRDwSF on each RNS-bearing waste container to mitigate the potential for a thermal runaway reaction. Per memo EM2016-5185, Justification for Not Incorporating the Pressure Relief Device with Supplemental Filtration (PRDwSF) to Nitrate Salt Bearing Waste Containers Processed with Waste Lock 770<sup>®</sup> (provided in Appendix A), the four POCs overpacked in 85-gallon containers are exempt from this process since it has been determined that they do not have a potential for a thermal runaway reaction given that Waste Lock 770® was introduced to the container as opposed to sWheat Scoop<sup>®</sup>.

#### 1.1 History of Containers

The containers in this campaign are Technical Area (TA) 55 legacy nitrate salt containers that were generated from 1979 to 1991. The TA-55 legacy nitrate salts are defined as non-cemented (unconsolidated) waste evaporator salts and evaporator bottoms. In 1979, plutonium operations at TA-55 began continuously producing evaporator salts and evaporator bottoms from plutonium recovery operations. Nitrate salt wastes were produced by passing a nitric acid solution containing plutonium through a column of tightly packed anion-exchange resin beads. This process of plutonium recovery resulted in a nitric acid solution containing various impurities and metal ions, including but not limited to magnesium, calcium, iron, aluminum, sodium, potassium, and americium. The contaminated nitric acid solution was sent to the evaporator and concentrated down to a volume of approximately 25 liters called "bottoms." The hot evaporator bottoms were moved to a chilling tray and cooled to room temperature. The bottoms were sampled and, if found to be below the economic discard limit, sent to a filtration boat. During filtering, the nitrate solution would precipitate out producing nitrate salts in a

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loose, moist, almost-saturated yellowish state varying in weight. The nitrate salts were placed into plastic bags for packaging into drums or were sent for cement fixation. The remaining filtrate solution was sent through a hydroxide precipitation process and re-filtered. The subsequent filtering process would capture the hydroxide precipitate salts in hard brownish cakes (hydroxide cakes) when dried. These hydroxide cakes were also bagged for packaging or cemented in cans. The remaining low activity filtrate and distillate solutions were transferred to the TA-50 Radioactive Liquid Waste Treatment Facility.

Unconsolidated nitrate salts in bags and cans of cemented nitrate salts were produced simultaneously from 1979 until 1991, when TA-55 changed to a monolithic cementation process. Most nitrate salts and hydroxide cakes were cemented in 1 gallon slip-fit lid cans or paint cans, although some unconsolidated nitrate salts remained in bags. Portland cement was the preferred cementation media. Gypsum cement was used for a short time but was found to dewater after fixing. Bags of unconsolidated salts were packaged in 55-gallon drums with 90 mil polyethylene liners and lead liners. Cemented cans were also packaged in 55-gallon drums, although polyethylene liners were not required. Drums could each contain up to a few dozen bags or thirty-five (35) cans. Bags of salts and cemented cans were typically not mixed together in waste drums. Other debris, such as leaded gloves, glass, or metals, was not routinely packaged together in the drums with the cans or bags. The drums were transferred to TA-54, Area G until a final disposition was determined.

Processing of the unconsolidated nitrate/suspect nitrate salt containers posed remediation challenges that were unique to this population of containers. Sodium nitrate and magnesium nitrate are the primary nitrate constituents of the TA-55 legacy waste and behave as oxidizers, which are prohibited at the Waste Isolation Pilot Plant (WIPP). Many of the containers also contained free liquids that leached from the nitrate salts over time which are also prohibited at WIPP. At Los Alamos National Security's direction, the LANL Carlsbad Office Difficult Waste Team authored a white paper, entitled "Amount of Zeolite Required to Meet the Constraints Established by the EMRTC Report RF 10-13: Application to LANL Evaporator Nitrate Salts," dated May 08, 2012, that, with Department of Energy (DOE) agreement, provided a technical solution for the unconsolidated nitrate salt containers at LANL. In order to meet the WIPP Waste Acceptance Criteria (WAC), the white paper determined a kitty "litter/zeolite clay" (zeolite) to nitrate salts mixing ratio that LANL would use at the Waste Characterization Reduction and Repackaging Facility (WCRRF) to remediate the nitrate salts to a non-oxidizing solid acceptable for disposal at WIPP. The recommended ratio was two (2) gallons zeolite for every one (1) gallon of nitrate salts.

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The choice of a zeolite clay based absorbent was predicated on the inorganic nature of zeolites. It is the inert nature of zeolites that leads to the reduction in the oxidizing potential of the nitrate salts. It has been determined that the absorbent used, an organic (i.e., wheat based) product called sWheat Scoop® kitty litter, did not mitigate, but may have actually activated the oxidizing potential of the waste.

Various neutralizing agents were used to neutralize the free liquids in the nitrate salt containers prior to mixing with the organic kitty litter and the processing ratio was modified to a three gallons absorbent to one (1) gallon nitrate salts ratio. Once absorbed, the waste mixture was packaged into daughter containers. Conditions were identified in the drums that may lower the temperature for reaction, including initial high acid concentration of free liquids; significant quantities (1 gal) of neutralized, absorbed free liquids; the presence of reactive or catalytic metals like magnesium, iron, or lead; the presence of bismuth containing glovebox gloves; and the presence of natural biological activity.

On May 15, 2014, the LANL Transuranic (TRU) Program received confirmation from WIPP that a breach was observed from a container in LANL Payload LA3606. Photographs of the payload were used to identify the breached container as nitrate salt daughter container LA00000068660. Since that determination, LANL has performed extensive experiments to identify the cause of the breach, as well as validate the disposition strategy LANL will use to remediate the remaining nitrate salt containers currently stored at LANL. The experiments suggest that the nitrate salt/organic kitty litter mixture alone would not produce the intense exothermic reaction required to cause the breach of container LA00000068660. However, this reaction could be generated from a series of exothermic reactions of the waste mixture when combined with nitric acid, glovebox gloves, lead shielding, metal impurities, and large quantities of absorbed liquids with low pH (0-2) from the parent container, all of which were evidenced from the review of remediation and characterization documentation in the contents of container LA00000068660.

Three (3) 55-gallon daughter containers have a mixture of nitrate salts, sWheat Scoop<sup>®</sup>, and Waste Lock 770<sup>®</sup>. Waste Lock 770<sup>®</sup> was added to unremediated nitrate salts (UNS) during a repack campaign prior to March 8, 2012. The sWheat Scoop<sup>®</sup> kitty litter was added to the UNS to absorb free liquids and reduce the oxidizing potential of the nitrate salts. The resulting mixture was repackaged in daughter containers that became part of the RNS waste stream.

After the release at WIPP from a LANL RNS waste container processed with sWheat Scoop®, the remaining RNS waste containers at LANL were identified and isolated. The containers were overpacked into SWBs and 85-gallon containers and stored at Area G, TA-54, Dome 375 Perma-Con®. There are some non-nitrate salt containers comingled with the RNS waste

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containers as well as dunnage containers. The RNS waste containers are being stored in a temperature controlled environment to mitigate the oxidizing behavior of the waste in the containers.

In May 2016, the lids of 46 SWBs were removed and PRDwSFs were installed on each RNS waste container in those SWBs. The remaining eight SWBs (containing POCs) will be opened to facilitate PRDwSF installation.

# 1.2 <u>Issues and Lessons Learned</u>

The PRDwSF installation process is a new activity resulting from lessons learned that indicated the significance of pressurization in creating a runaway thermal reaction.

#### 1.3 Waste Campaign Container Description

Table 1 below shows that the population of containers in this waste campaign includes one (1) LA-CIN01.001 cemented waste stream, ten (10) LA-MHD01 debris waste streams, and forty-five (45) LA-MIN02 absorbed waste streams. Appendix B provides a detailed description of each waste stream derived from Central Characterization Project (CCP) document CCP-AK-LANL-006-REV-13. Real-time radiography (RTR) reports state the containers appear to be in good condition.

**Table 1. RNS CCP Acceptable Knowledge Waste Streams** 

Note: Data as of June 1, 2016

oter Buta as or suric 1, 2010		
<b>Container Type</b>	Waste Stream	Count
SWB-55-GAL		48
	LA-CIN01.001-Cans	1
	LA-MHD01.001	10
	LA-MIN02-V.001	37
SWB-POC		8
	LA-MIN02-V.001	8
<b>Grand Total</b>		56

#### 1.4 Chemical Constituents

LANL designated the remaining RNS waste containers as "Ignitable" and assigned Environmental Protection Agency (EPA) Hazardous Waste Number D001 after independent reactivity testing on surrogate samples containing sWheat Scoop® and sodium nitrate salt. The RNS waste containers also carry the following EPA Hazardous Waste Numbers listed in the

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Table 2 below, depending on waste stream profile assignment. There are three containers in this campaign identified to have liquid; 68631, 69036 and 69298. They are also assigned Hazardous Waste Number D002 for corrosivity. All containers identified to have liquid, not already in an SWB, will be placed on secondary containment.

Table 2. EPA Waste Codes for Waste Stream Profiles 42366 and 42333

Waste Stream Profile 42366 EPA Numbers		Waste Stream Profi	le 42333 EPA Numbers
D001A	D039	D001A	F001E
D001B	D040	D004A	F001H
D002A	F001E	D005A	F002A
D004A	F001H	D006A	F002C
D005A	F002A	D007A	F002D
D006A	F002C	D008A	F002H
D007A	F002D	D009E	F005E
D008A	F002H	D010A	F005G
D009E	F003A	D011A	F005H
D010A	F003B	D018	
D011A	F003F	D019	
D018	F003G	D021	
D019	F003I	D022	
D021	F005E	D035	
D022	F005G	D038	
D035	F005H	D039	
D038		D040	

Based on generator information, this waste stream does not include wastes containing or contaminated with polychlorinated biphenyls or beryllium. However, containers 69595, 69559, and 69568 were processed in the WCRRF waste characterization glovebox (WCG) following a campaign involving beryllium contaminated waste before the interior of the WCG was decontaminated to a level below the release limits. Thus, as a precaution, these drums were labelled as containing or contaminated with beryllium.

The minimum and maximum values provided in Table 3, bounds the population that will undergo the PRDwSF installation process under this waste campaign. The data provided below will also be used to determine whether this population of waste containers and associated waste streams fall within existing facility constraints and Technical Surveillance Requirements (TSRs) or if procedural or facility changes are required.

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Table 3. Minimum and Maximum Values for Individual RNS Container

Container Count	Min PECi	Max PECi	Min EC PECi	Max EC PECi	Min FGE	Max FGE	Min Gross Wt (lbs)	Max Gross Wt (lbs)	Min TOTAL DOSE (mR/hr)	Max TOTAL DOSE (mR/hr)
56	0.30	39.12	0.30	39.12	0.29	173.19	85.00	510.00	.90	82.00

Note: Data as of June 1, 2016;

EC PECi = equivalent combustible plutonium equivalent Curies; FGE = fissile gram equivalent; Weight = lbs.; Dose = total surface dose rate (mR/hr). The weight associated with each container is from the RTR Batch Data Report form; not from WCATS database.

# 1.5 <u>Facility Limits</u>

The 56 RNS waste containers are proposed to undergo the installation of a PRDwSF in accordance procedures AREAG-WO-DOP-1340, TA-54 Area G Remediated Nitrate Salt SWB Lid Removal, AREAG-WO-DOP-1343, TA-54 Area G Remediated Nitrate Salt Container PRDwSF Installation, AREAG-WO-DOP-1347, Assembly of PRDwSF, and AREAG-WO-DOP-1369, TA-54 Area G RNS POC PRDwSF Installation in order to minimize the potential for pressurization resulting in a runaway reaction. The proposed activities will be performed at TA-54 Area G Dome 375 Perma-Con® where the RNS waste containers are currently stored and is authorized by Evaluation of the Safety of the Situation (ESS) AREAG-ESS-14-002, Potential Inadequacy of the Safety Analysis (PISA) – TRU Waste Drums Containing Treated Nitrate Salts May Challenge the Safety Analysis. TA-54, Area G is categorized as a DOE non-reactor Hazard Category-2 facility. TA-54, Area G Dome 375 Perma-Con® has the following facility limitations:

• Material-At-Risk (MAR) – Dome 54-0375 is designated as a Storage Area with only COMPLIANT METAL CONTAINERS with a limit of less than 22,000 plutonium equivalent Curies (PE-Ci). However, Dome 54-0375 is currently only allowed a total MAR of less than or equal to 900 PE-Ci (ESS-14-002, Specific Administrative Control [SAC] 12-1). This requirement is implemented by EP-AREAG-SO-1372, TA-54-Area G Operating Requirements. Currently, the total Perma-Con® MAR inventory is ~797 PE-Ci which remains bounded by the 900 PE-Ci MAR limit.

Per AREAG-ESS-14-002-R.6.1, installation of the PRDwSF and related support activities will be performed inside the Dome 54-0375 Perma-Con® which will remain a compliant container storage area. The RNS waste containers are considered compliant metal containers throughout the activities covered by the ESS. The ESS activities are not considered sort, segregate, size reduction, and repackaging or process activities as defined under TA-54 Area G TSRs. Controls on venting in the TA-54 Area G TSRs, specifically SACs 5.7.14, 5.7.15, and 5.7.16, apply to unvented containers and are not pertinent to this ESS.

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 Per CSLA-13-064, TA-54 Area G, 55-Gallon Drum Criticality Safety Requirements for General Storage Areas, the following criticality safety requirements apply to 55-gallon containers overpacked in 85- and 110-gallon containers.

#### **Low FGE Containers**

- o Less than 200 fissile gram equivalent (FGE)
- o No limitation on number of containers
- Stacks less than 3 containers high
- Staging boundary must be greater than 10 feet from high FGE container collections
- o Containers may be in contact
- o May be commingled with low FGE SWBs less than 325 FGE

Table 3 shows a maximum FGE value for RNS waste containers of 173.19, which is less than the 200 FGE limit.

The number of containers that may be transported on a pallet is the same as the number allowed for staging.

Separation Distance - Outer SWBs and 85 gallon overpacks containing POCs shall maintain greater than or equal to 2 feet of separation distance. This meets Isolation Plan and LANL Hazardous Waste Facility Permit requirements (2 feet minimum) and ESS-14-002, SAC requirements (1 foot minimum).

Appendix C, Individual Waste Container Values, provides the following waste data/values for each individual container based on the existing data in Waste Compliance and Tracking System (WCATS) as of March 9, 2015.

- Package ID
- Parent ID
- Overpack ID
- Container Type
- Gross Weight
- Fissile Grams Equivalent Values
- Dose Rates (mRem/hr)
- PE-Ci value
- Equivalent Combustible PE-Ci value
- Waste Steam ID

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# 1.6 <u>Pre-screen or Certified Real-Time Radiography</u>

The containers in this waste campaign were screened by high energy (HE)-RTR/RTR and have been reviewed by CCP/Management. Appendix D, RNS Waste Parameters, details the container IDs and waste parameters associated with each RNS waste container based on HE-RTR or RTR screening results. HE-RTR/RTR videos, in conjunction with the Safety Evaluation Data Sheets (SEDS), will be provided to the operators prior to installation of the PRDwSF. RTR videos associated with the RNS waste containers are located at \\Win\nwis\Projects\TRU Production Controls\RTR Videos\57 Remediated Nitrate Daughter RTR Videos.

The 56 RNS waste containers could further be described as follows:

Forty-eight (48) 55-gallon containers

- o Forty-five (45) 55-gallon daughter containers of nitrate salt and sWheat Scoop®
  - Two (2) 55-gallon containers contain an open 30-gallon container inside with nitrate salt and sWheat Scoop®
- Three (3) 55-gallon daughter containers contain a mixture of nitrate salts, sWheat Scoop®, and Waste Lock 770®

Eight (8) POCs

o Eight (8) POC daughter containers of nitrate salt and sWheat Scoop®

In this waste campaign, there are three (3) containers with liquid ranging from  $\sim$ 10 milliliters (mL) to  $\sim$ 20 mL.

The RNS 55-gallon and POC containers are overpacked in SWBs and their configuration is provided in Appendix E, RNS Overpack Configuration. Review of CCP RTR Batch Data Report and the video for the RNS waste containers indicate that each RNS waste container was configured with an outer bag and a cardboard/fiberboard liner inside the outer bag. The waste in the RNS waste container is largely comprised of the following waste matrices:

- Homogeneous solids nitrate salts absorbed with organic kitty litter (sWheat Scoop®)
- Scrap lead
- Radiation shielding glovebox gloves
- Rubber gloves
- Scrap metal
- Plastics rigid liner, plastic bags, plastic sheeting
- Cardboard/fiberboard liner
- Cellulose
- Liquid

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#### 2. PROGRAMMATIC CONSIDERATIONS

# 2.1 Receipt and Storage

WC 303 addresses the installation of PRDwSF to minimize the potential for pressurization of the RNS-bearing waste containers. The 56 RNS waste containers associated with this campaign currently have WIPP-approved NFT filter vents installed in the ¾ inch (in.) bung opening. A pressure relief device and NFT filter vent will be inserted into the 2 in. bung opening on the lid of the 55-gallon RNS waste container. The NFT filter on the PRDwSF will be replaced with a high flow high-efficiency particulate air (HEPA) filter.

The lid of the POC will be removed, the ¾ in. NFT filter on the inner pipe component will be removed, and a new standard 55-gallon drum lid with a ¾ in. bung and 2 inch bung will be placed on the POC. A ¾ in. NFT filter will be installed in the ¾ in. bung on the POC. A PRDwSF with a HEPA filter will be installed into the 2 inch bung on the lid of the POC.

There are no new requirements associated with the Isolation Plan as a result of the installation of the PRDwSF. Per the Isolation Plan, temperature measurements are taken daily from the top surface of the overpack container using a thermocouple, infrared thermometer, or infrared imaging camera.

Per AREAG-ESS-14-002, R6.1, the TA-54-375 Perma-Con® ambient air temperature is maintained at less than or equal to 75° Fahrenheit (F). There will be no new overpacking requirements as a result of the installation of the PRDwSF. Daily visual inspection of the RNS bearing waste containers continues under AREAG-ESS-14-002, R6.1.

Containers designated for installation of a PRDwSF at Dome 54-0375 must meet the following criteria prior to installation and related support activities as directed by AREAG-ESS-14-002 R6.1:

- Hydrogen concentration in the headspace gas less than 1% (10,000 parts per million [ppm])
- Carbon dioxide and nitrous oxide concentrations in the headspace gas Levels that do
  not depart from expected trends within the 36 hours prior to RNS waste container bung
  removal.

#### 2.2 Transport/Handling

Per AREAG-ESS-14-002 R6.1, the movement of RNS-bearing waste containers shall be limited to minimal movement necessary to perform PRDwSF installation and related support

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activities. The RNS waste containers will remain in the Dome 54-0375 Perma-Con® following the installation of the PRDwSF.

Per the requirements of the Isolation Plan, Section IV (8), overpack containers have been stored with a minimum of 2 feet between containers and will not be moved prior to, or after, the addition of the PRDwSF to the 55-gallon inner RNS waste containers.

#### 2.3 Remediation/Treatment

#### 2.3.1 Technical Basis for PRDwSF Installation

Extensive studies have been performed on the RNS waste to characterize and better understand the reactive nature of the material. Testing has included laboratory testing and full scale container testing of surrogate nitrate salts and mixtures of the surrogate salts with sWheat Scoop® kitty litter.

As a result of this testing, the importance of temperature and pressure on the reaction thermodynamics and kinetics has become clear. Details on the impact temperature control and pressure relief has on mitigating potential runaway reactions are provided in Appendix F, "Technical Basis for the Addition of a Safety Class Pressure Relief Device, Supplementation Filtration, and Choice of Operational Temperature for Addition of the System." (EM2016-5070)

Full scale container tests were used to understand the reaction behavior of nitrated surrogate material. The material tested and placed in the containers was formulated to mimic the blends thought to be found in the RNS waste containers. These tests provided information that was used to develop guidance on the design and performance requirements of a pressure control assembly to mitigate potential runaway reactions. Test data from Drum D test was used to calculate the gas generation rates of the RNS waste when heated to 60° Celsius (140° Fahrenheit [F]). The gas generation rate calculation is presented in Appendix G, "Estimated Gas Generation Rate of Surrogate RNS Waste" and is based on the test data from Drum D of the full scale container tests described in the report "Drum Scale Testing of the Thermolytic Response of a Remediated Nitrate Salts (RNS) Surrogate Waste Mixture" (LA-CP-16-20038). The calculation showed that the rate of gas generation reached 3.77 liters per minute (L/min) just prior to the container lid being ejected from the pressure build up in the container and was 2.67 L/min averaged over the last minute. The pressure in the container just prior to lid ejection was 31 pounds per square inch gauge (psig). Drum C test information also showed that the pressure relief caused by rupture of the <sup>3</sup>/<sub>4</sub> in. NFT filter at 14 psig led to the "rapid and complete quench of the late-stage thermal runaway" (LA-CP-16-20038).

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Prior to installing the PRDwSF, the configuration of the RNS waste containers with a ¾ in. NFT vent filter (NucFil®-019 DS) provides normal ventilation rate of 200 milliliters per minute (mL/min) of air flow at a pressure of 1 in. water column (WC). This is almost 20 times less than would be required to handle the flow of the gas generated during Drum D full scale test and would likely result in an increase in internal pressure within the container if not supplemented by another means of flow relief. In order to ensure pressure build up does not occur and associated reaction rates are not accelerated, additional engineered controls have been identified for the 55-gallon RNS waste container to reduce the potential for a runaway reaction.

The eight POCs contain a 12 in. inner pipe component. A general configuration of the 12 in. inner pipe component is shown in Figure 1. The lid of the 12 in. inner pipe component includes a ¾ in. NFT filter that is fed by four 0.089 in. diameter holes drilled through the lid. These holes provide a leak path through the lid of the inner pipe component for any gas generated by the contents in the inner pipe component. Appendix H provides the "Drum POC Lid Vent Flow Rate Evaluation, CAL-99-MULT-01257." The contents of the inner pipe component are enclosed in a vented bag containing a 1.5 in. diameter BOP HEPA filter (Model # 6CPVC-1.5-2SPVC) shown in Figure 2.

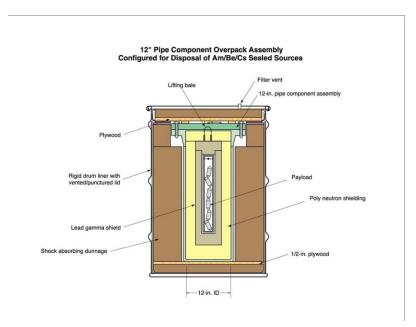


Figure 1. 12 in. Pipe-component-overpack assembly configuration

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Figure 2. BOP HEPA filter on bag in 12 in. Inner Pipe Component

The observed flow of gas generated from Drum D test prior to lid ejection was 2.67 L/min (averaged over 1 min) at 31 psig. The BOP bag HEPA filter and the four holes in the inner pipe component lid both allow for more than 10 times the flow of gas seen just prior to lid ejection in Drum D test. The calculated flow rate of gas through the four drilled holes in the inner pipe component lid is 15 L/min @ 1 in. WC and 162 L/min at 4 psig, well above the peak flow rate seen in the Drum D test. Flow verification through these holes will be completed prior to installation of the PRDwSF on drums containing pipe components. The BOP filter provides 3 L/min of flow @ 1 in. of WC and 47 L/min @ 1 psig. The results of the flowrate testing of the bag filter are presented in Appendix I, "Flowrate testing of the filter bag LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig."

#### 2.3.2 PRDwSF Performance Requirements (Process Engineering Requirements)

Requirements for the equipment to reduce the potential for pressure build up in the RNS 55-gallon drums and POC's include:

• Flow capability of the supplemental ventilation should exceed 10 times those found in the full scale container tests or 37.7 L/min @ 1 in. of WC.

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• Flow capability of the pressure relief device should exceed 100 times those found in the full scale container tests or 377 L/min @ disc rupture pressure to remove excess gas upon rupturing.

- Pressure for rupture of the pressure relief device should be less than 4 psig.
  - o This is lower than the 14 psig observed in Full Scale Drum C Test that safely quenched the reaction upon pressure relief.
  - This represents a safety factor greater than 2 when compared to the 11.3 psig pressure which properly closed 55-gallon drums are required to withstand (Test and Evaluation Document for the U.S. Department of Transportation Specification 7A Type Packaging (DOE/RL-97-57, volume 2, Rev. 0-D).
  - o Pressure for rupture of the pressure relief device should be greater than 1 pounds per square inch (psi) to ensure against inadvertent rupture or requiring very large surface area discs that would be difficult to fabricate and field.
- PRDwSF assembly, including the pressure relief device and the supplemental filter should:
  - o utilize the 2 in. drum bung for attachment and sealing (POC lids will be replaced with standard 55-gallon drum lids)
  - o fit within the footprint of the drum lid
  - o not impede container movement for lifting or transport
  - o provide for support of the supplemental filter to stabilize the assembly
  - o be less than 10 inches tall to minimize torque on the drum lid in order to simplify installation and allow for ease of container handling and movement

#### 2.3.3 PRDwSF Design Requirements

The following design requirements were identified in the design and for securing elements and components of the pressure control system. A conceptual design is shown in Figure 3 and the associated components are identified in Table 4:

#### Rupture Disc:

Rupture disc relief pressure: Less than 4 psig and greater than 1 psig

Rupture disc size: 1 in. diameter

Minimum Post Rupture Flow Rate: 377 L/min @ disc rupture pressure
Performance standard: ASME Section VIII Division 1

Material of construction: stainless steel
Bolt strength: 30,000 psi

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Piping:

Size: less than 2 in. diameter

Minimum Piping Flow Rate: 377 L/min @ disc rupture pressure

Pressure Rating: 50 psig

Material of construction: stainless steel

Performance standard: Schedule # 40S minimum

Drum bung bushing thread: 2 in. NPS threads
Thread Sealant: Teflon tape > 4 mils

Supplemental Filter:

Minimum flow @ 1 in. WC: 37.7 L/min @ 1 in. of WC

Material of construction: stainless steel

Max operating temp: 250°F

HEPA performance: 99.97% @ 0.3 micron
Weight: less than 10 pounds

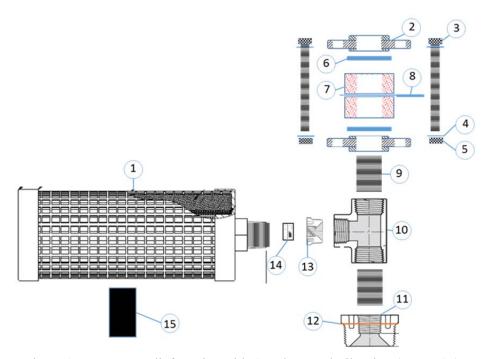


Figure 3. Pressure Relief Device with Supplemental Filtration (PRDwSF)

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Table 4. Parts Description for Proposed PRDwSF

Item #	Description	Material	Spec	Qty.	ML
1	Porvair Filter F2902	SS 316	F2092-HEPA	1	3
2	1" NPT threaded 150 # flange	SS 316	ANSI B16.5	2	1
3	1/2" X 5" - 13 stud	4140 Alloy	ASTM 193 Gr B7	4	1
4	Deleted (intentionally omitted)				
5	1/2" - 13 heavy hex nut	4140 Alloy	ASTM 193 Gr B7	4	1
6	Universal Gylon gasket 3500, 150# ASME	Gylon	ASME B16.21	2	1
7	Rupture Disc Holder	SS 316	CDD15541A0001	1	1
8	Rupture Disc	SS 316	SC16187A0001	1	1
9	1" NPT x 2.0" NPT nipple	SS 316	ASME B16.11	2	1
10	1" X 1" X 1" NPT Tee	SS 316	ASTM A351	1	1
11	2" NPS X 1" NPT bushing	SS 316	ASME B16.11	1	1
12	Gasket - Nucfil	Neoprene	Dr# 90000204	1	3
13	1"NPT x 3/4" NPSM bushing	SS 316	ASME B16.11	1	1
14	NFT 3/4" NPSM - 14 HEPA vent	SS 304	Nucfil 013	1	3
15	Support Saddle	Aluminum		1	3

#### 2.3.4 PRDwSF Installation Approach for 55-Gallon Drums

The installation of PRDwSF provides additional venting capability and pressure relief for 55-gallon containers of RNS waste. The 55-gallon containers located in an SWB will first be accessed by removing the SWB lid. Once the 55-gallon RNS waste container is accessible, the 2 in. bung will be removed, the internal bag will be perforated, and the PRDwSF will be installed in the 2 in. bung opening. If the supplemental high flow HEPA filter is not received by the time PRDwSF assembly installation has been initiated, a ¾ in. NFT filter vent will be installed temporarily where the supplemental filter will reside. Once the supplemental filter is received, the ¾ in. NFT filter will be removed and replaced with the supplemental high flow HEPA filter. No nitrate salt waste, except for residual on the perforating tool, will be removed from the RNS waste container.

Three procedures address the processes for SWB lid removal, pressure relief device assembly, and installation of the PRDwSF. AREAG-PLAN-1373, TA-54 Area G Implementation Plan for AREAG-ESS-14-002, R6.1, defines the actions necessary for implementation of the changes introduced in AREAG-ESS-14-002, R6.1.

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The proposed path forward is shown in the process flow diagram for installation of the PRDwSF in standard 55-gallon drums in Appendix J, "Flowchart for PRDwSF Installation in Standard 55-Gallon Drums." The following steps will be followed for installation of the PRDwSF once the SWB lid has been removed.

#### 1. Select Container

Container selection will be based upon MAR content, accessibility, and location in Dome 375.

# 2. Approval for PRDwSF Installation Operations

- a. Personnel trained and qualified
- b. Round sheets and inspection sheets completed
- c. SEDS for container available
- d. Equipment certified and calibrated
- e. Tools and materials available and inspected
- f. Personal protective equipment (PPE) available and in working order
- g. Secondary waste containers prepped and available
- h. Check sheets available
- i. PRDwSF available
- j. Headspace gas analysis from container acceptable

#### 3. Visual Inspection of Container

a. Although still in the SWB, the visible areas of the container will be inspected for abnormal condition, to ensure its integrity is acceptable and that no special action is required.

# 4. Verifications

- a. Verify Perma-Con® temperature is less than or equal to 75°F for the previous two days.
- b. Verify the container external temperature is not greater than 10°F above Perma-Con® cell temperature.
- c. Verity headspace gas sampling results within last 36 hours are less than 10,000 ppm hydrogen and both carbon dioxide and nitrous oxide concentrations are consistent with expected trends.

#### 5. Remove the 2 in. bung from the 55-gallon container

- a. Unscrew the 2 in. bung from the container.
- b. Remove the bung.

# 6. Borescope examination of the 55-gallon container

- a. Insert a borescope into the bung hole and examine the internal configuration of the waste within the container.
- b. If there is no indication of a chemical reaction, continue to Step 7.
- c. Clean borescope.

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#### 7. Perforate the bag in the 55-gallon container

a. Using a non-conductive, sharp instrument, perforate the container inner bag.

- b. Remove the perforating tool from the drum, swiping as removed.
- c. Dispose of perforating tool and swipe material.

#### 8. Insert a pressure relief device and HEPA filter or NFT NucFil filter in the 2 in. bung

- a. Prepare a PRDwSF shown in Figure 3 according to procedure and document required information.
- b. Install 2 in. x 1 in. bushing (11) with gasket (12) into 2 in. bung opening.
- c. Torque the 2 in. x 1 in. bushing (12) to 15 foot-pounds.
- d. Thread the preconfigured PRD assembly into the 2 in. bushing and hand tighten plus one revolution to compress the gasket.
- e. Holding the 2 in. x 1 in. bushing in place, orient the <sup>3</sup>/<sub>4</sub> in. supplemental vent (14) in the direction of the <sup>3</sup>/<sub>4</sub> in. bung on the lid.

#### 9. Install Porvair supplemental vent

- a. Remove the 1 in. x <sup>3</sup>/<sub>4</sub> in. bushing and NFT filter vent from the PRDwSF assembly.
- b. Thread the Porvair supplemental vent into 1 in. x 1 in. x 1 in. NPT tee (10) and hand tighten plus one revolution.
- c. Insert the support saddle

# 2.3.5 PRDwSF Installation Approach for POCs

The lid will be removed from the POCs and the ¾ in. NFT filter removed from the inner pipe component lid. The POC will be fitted with a lid that has a ¾ in. NFT filter on the ¾ in. bung opening and an open 2 in. bung. After the lid is attached to the POC, a PRDwSF will be installed in the 2 in. bung opening in the lid.

The proposed path forward is shown in the process flow diagram for installation of the PRDwSF for POCs in Appendix K, "Flowchart for PRDwSF Installation in POCs." The following steps will be followed for installation of the PRDwSF on a drum that contains an inner pipe component once the SWB lid has been removed.

#### 1. Select Container

 Container selection will be based upon MAR content, accessibility, and location in Dome 54-0375.

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# 2. Approval for PRDwSF Installation Operations

- a. Personnel trained and qualified
- b. Round sheets and inspection sheets completed
- c. SEDS for container available
- d. Equipment certified and calibrated
- e. Tools and materials available and inspected
- f. Personal protective equipment (PPE) available and in working order
- g. Secondary waste containers prepped and available
- h. Check sheets available
- i. PRDwSF available
- j. Headspace gas analysis from container acceptable

# 3. Visual Inspection of Container

a. Although still in the SWB, the visible areas of the container will be inspected for abnormal condition to ensure its integrity is acceptable and that no special action is required.

#### 4. Verifications

- a. Verify Perma-Con<sup>®</sup> temperature is less than or equal to 75°F for the previous two days.
- b. Verify the container external temperature is not greater than 10°F above Perma-Con® cell temperature.
- c. Verity headspace gas sampling results within last 36 hours are less than 10,000 ppm hydrogen and both carbon dioxide and nitrous oxide concentrations are consistent with expected trends.

#### 5. Remove the lid from the 55 gallon drum containing the inner pipe component

- a. Loosen the bolt on the bolted drum ring.
- b. Remove the drum ring once the bolt has been completely loosened.
- c. Remove the lid on the POC containing the inner pipe component.

#### 6. Remove the 3/4" NFT filter on the inner pipe component

- a. Remove any plywood and dunnage atop the lid of the inner pipe component.
- b. Loosen the ¾ in. NFT filter from the lid of the inner pipe component and remove.

#### 7. Verify flow through the four holes in the pipe component lid

- a. Set the syringe plunger in the flow test assembly to approximately 30 ml.
- b. Thread a flow test assembly into the ¾ in. opening in the pipe component lid.
- c. Discharge the syringe plunger to the bottom of the syringe.
  - If it does not allow for air injection, stop and go to Step 7.d.
  - If it discharges all 30 ml, then reset the plunger to approximately 30 ml.
  - If the plunger cannot be lifted to the 30 ml level, go to Step 7.d.
  - If the plunger can be retracted to the 30 ml level, go to Step 7.d.
- d. Remove the flow test assembly from the <sup>3</sup>/<sub>4</sub> in. opening in the pipe component lid.

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#### 8. Install a new 55-gallon lid

a. Place a new 55-gallon drum lid with a ¾ in. NFT filter installed and an open 2 in. bung on the drum containing the inner pipe component.

b. Replace the bolted drum ring around the lid and tighten the securing bolt.

#### 9. Insert a pressure relief device and HEPA filter in the 2 in. bung

- a. Prepare a PRDwSF shown in Figure 3 according to procedure and document required information.
- b. Install 2 in. x 1 in. bushing (11) with gasket (12) into 2 in. bung opening.
- c. Torque the 2 in. x 1 in. bushing (12) to 15 foot-pounds.
- d. Thread the preconfigured PRD assembly into the 2 in. bushing and hand tighten plus one revolution to compress the gasket.
- e. Holding the 2 in. x 1 in. bushing in place, orient the ¾ in. supplemental vent (14) in the direction of the ¾ in. bung on the lid.

#### 9. Install Porvair supplemental vent

- a. Remove the 1 in. x ¾ in. bushing and NFT filter vent from the PRDwSF assembly.
- b. Thread the Porvair supplemental vent into 1 in. x 1 in. x 1 in. NPT tee (10) and hand tighten plus one revolution.
- c. Insert the support saddle.

#### 2.4 Characterization

No new daughter container or newly generated waste containers will be generated and the physical/chemical components of the waste are not expected to change during this campaign; therefore, no new LANL characterization is required. A waste profile is needed for secondary waste generated during the PRDwSF installation. This waste will likely consist of perforating tools, bungs, drum lid, bushings, NFT filter vents, and Spiltfyter Hazmat Sorbent SM pads. Compactible low-level waste (LLW) such as PPE, nitrile gloves, and respirator cartridges will be generated under waste profile 24230, Waste from Maintenance and Operations at TA-54-G, LLW-NTS.

#### 2.5 Certification

The scope of this Waste Campaign Plan does not include certification of the RNS waste containers. The 56 RNS waste containers are on CCP Acceptable Knowledge (AK) processing hold. A processing hold was placed on the 60 RNS waste containers suspected of or known to contain nitrate salts until the waste stream can be remediated and the new daughter containers are processed through CCP characterization and certification for reassignment to the appropriate waste streams. This Nonconformance Report (NCR)/AK Hold and subsequent review of generator data/remediation documentation identified the population of containers with absorbed nitrate salt destined for remediation processing requirements.

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Below is the list of active LANL NCRs associated with RNS waste containers.

• NCR-2014-475 – Nitrate salt containers mis-labeled during overpack operations in relation to the isolation plan. (Detailed Description of NCR: Field configuration of overpacked nitrate salt labels is not consistent with information in WCATS.)

 NCR-2015-449 – RNS waste containers with liquid not managed in accordance with Permit. (Detailed Description of NCR: SWBs 68631, 69036 and 69298 have been identified as containing free liquid but are not on secondary containment or labeled appropriately. These SWBs hold remediated nitrate salt containers and are currently in isolation in TA-54 Area G Dome 375 Perma-Con.)

Secondary waste generated during PRDwSF installation is expected to be mixed-LLW (MLLW) which will be certified by waste packaging certifiers prior to closure of containers.

# 2.6 Shipping

The scope of this Waste Campaign Plan does not include shipment of the RNS waste containers. The shipment of secondary waste generated will be the subject of a future waste campaign plan specific to LLW and MLLW.

# 2.7 **Programmatic Equipment Summary**

The following equipment will be needed for installation of the PRDwSF:

- Calibrated direct reading air monitoring instrument(s) or detector tubes capable of measuring combustible gases, oxygen, carbon monoxide, and nitrogen dioxide
- MAC-21 air mover and trunk hoses
- Ventilation adaptor
- Calibrated infrared thermometer
- Non-conductive perforating tool (Used for 55-gallon drum only)

#### 2.8 Processing Materials Summary

The following materials will be needed for installation of PRDwSF:

- Spiltfyter Hazmat Sorbent SM (polypropylene) pads
- Yellow vinyl tape
- Plastic bags for waste

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# 2.9 <u>Commodities Summary</u>

The 56 RNS waste containers will require the following:

Commodity	Count
PRDwSF	56
Secondary waste container-55 gallon drum	3
3⁄4 in. NucFil filters-on hand	56
Standard 55-gallon drum lid	8

# 2.10 Processing Rate Summary

The PRDwSF installation is expected to be performed at a rate of four per day with a two person team. The process will initiate with a few low MAR containers and then transition from highest to lowest MAR.

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#### 3. FACILITY CONSIDERATIONS

#### 3.1 Environmental Requirements

The requirements of the LANL Hazardous Waste Facility Permit and the Isolation Plan, remain in full effect during the PRDwSF installation process. The affected RNS waste containers shall be maintained in good condition per LANL Permit Section 3.2. If an RNS waste container is not in good condition or begins to leak, the permit requires that the container be overpacked or the waste transferred into a container with good condition.

After removal of the SWB lids, the internal 55-gallon RNS waste containers will be stored within the open SWBs. The RNS waste containers will be kept closed except when adding the PRDwSF to the container lid, as required by LANL Permit Section 3.5. Appropriate labels, compliant with LANL Permit Section 3.6, will be applied to the lids of each RNS waste container.

After the addition of the PRDwSF, the 55-gallon waste containers will not be removed from the open SWB overpacks or elevated to meet the requirements of LANL Permit Sections 3.7.1(1) or 3.7.2(1)(a). This storage configuration will continue to be protective of human health and the environment because daily visual inspections, temperature measurement, and headspace gas sampling on the 55-gallon containers will continue as described in the Isolation Plan. Any spilled or leaked waste will managed appropriately.

All records from the PRDwSF process, as well as those resulting from related inspections, temperature measurement, and headspace gas sampling will be maintained as part of the LANL Hazardous Waste Facility Operating Record.

Potential wastes from the PRDwSF installation process include MLLW, Green is Clean PPE (especially gloves) that should be evaluated for radioactive contamination after work is performed, and low-level radioactive PPE that fails Green is Clean acceptance criteria. The MLLW waste will have the same EPA Hazardous Waste Numbers as the RNS waste.

#### 3.2 Nuclear Safety Basis Requirements

AREAG-ESS-14-002, R6.1 provides nuclear safety basis requirements. AREAG-PLAN-1373 was prepared and defines the actions necessary for implementation of the changes introduced in AREAG-ESS-14-002 R6.1 Table 5 provides an overview of the Administrative Controls (ACs) Special Administrative Controls (SACs), Limiting Conditions of Operations (LCOs), Surveillance Requirements (SRs), and Structures, Systems, and Components (SSCs) identified

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in Revision 6.1 of AREAG-ESS-14-002. Controls provided in AREAG-ESS-14-002 are unnumbered. To facilitate field implementation of the associated surveillances, numbers have been assigned and are provided in the table below.

Revision 6.1 of AREAG-ESS-14-002 was approved by Safety Evaluation Report, SER-AREA G-ESS-14-002, Revision 5.0. While the Safety Evaluation Report modified some of the control listed in AREAG-ESS-14-002, Revision 6.1, none were modified in such a way that impacts installation of the PRDwSF as described in this document.

Table 5. AREAG-ESS-14-002, R6.1 Summary of Controls					
Number	Control	Frequency			
SAC 01/ SR 4.ESS.5.1	PermaCon ambient air temperature is ≤ 75°F PermaCon ambient air	Daily between 1pm and 5pm			
SAC 01/ SR 4.ESS.5.2	temperature is $\leq 75^{\circ}F$ for previous two days.	4 hours prior to initiating overpack lid removal			
SAC 02-A	Visual inspection of closed SWBs/Overpacks	Daily			
SAC 02-B	Visual inspection of RNS container	Immediately after overpack lid (excluding 85-gallon overpacks) is removed     Daily thereafter			
SAC 03	Visual inspection of Overpack	<ul> <li>Prior to filter vent removal</li> <li>Prior to overpack bolt removal</li> <li>Prior to overpack lid removal</li> </ul>			
SAC 04	Visual inspection of RNS container and inner bag	<ul> <li>Prior to overpack bolt removal</li> <li>Prior to 55-gallon drum lid removal for POC</li> </ul>			
SAC 05	Headspace Gas Sampling	<ul> <li>Prior to removing the SWB filter vent(s), plug(s), unbolting the lid</li> <li>Prior to removing RNS drum bung, a POC 55-gal drum lid, the NFT filter from a POC's inner pipe component</li> </ul>			
SAC 06	Overpack/RNS waste container surface temperature	<ul> <li>Prior to SWB overpack lid removal</li> <li>Prior to removing 55-gal drum lid</li> <li>Prior inner pipe component NFT filter removal</li> </ul>			
SAC 07	SWB/ POCs 1-ft Spacing	At all times			
SAC 08	RNS waste container movement restrictions	At all times			
SAC 11	CAM Alarm Response	At all times			
SAC 12-1 SAC 12-2 SAC 12-3	MAR in PermaCon ≤ 900 PE- Ci No other MAR stored in Dome 375 No other MAR stored within 60 ft of PermaCon	At all times			

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Tab	Table 5. AREAG-ESS-14-002, R6.1 Summary of Controls (continued)				
Number	Control	Frequency			
SAC 13	Defensible space requirement	Vegetation within 65 ft of the PermaCon shall be cut weekly (May-Oct)			
SSC 1	PRDwSF for RNS Waste Containers	At all times once installed			
SSC 2	54-0375 PermaCon Fire Suppression System	At all times			
SSC 3	54-0375 PermaCon Ventilation System	At all times			
AC 1	Conduct of Engineering Program	At all times			
AC 2	Conduct of Maintenance Program	At all times			
AC 3	LAFD Pre-Incident Plan to include Dome 375 priority statement	At all times			
AC 4	Emergency Management	<ul> <li>Area G emergency response procedure shall include actions to protect RNS waste if there is imminent fire hazard.</li> <li>Fire blankets shall be available with a procedure to deploy them.</li> <li>Fuel mitigation/tree thinning performed in Area G canyons.</li> </ul>			

# 3.3 Criticality Safety Requirements

The following Criticality Safety Evaluations have been prepared for PRDwSF Installation:

- 1. NCS-CSED-16-015, Criticality Safety Evaluation for Opening Overpacks Containing RNS-bearing Drums in Dome 375 at TA-54, 2016-03-17.
- 2. NCS-CSED-16-031, Criticality Safety Evaluation for PRDwSF Installation in RNS-bearing Drums in Dome 375 at TA-54, 2016-04-14.
- 3. NCS-CSED-16-046, Criticality Safety Evaluation for the Replacement of Lids on RNS-bearing Drums in Dome 375 at TA-54, 2016-04-14.
- 4. NCS-CSED-16-053, Criticality Safety Evaluation for PRDwSF Installation in RNS-bearing POC Drums in Dome 375 at TA-54, 2016-04-14

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# 3.4 Radiological Work Permits

New Radiological Work Permit and a New Activity ALARA review is required for this activity.

#### 3.5 <u>Facility Modifications</u>

Except for the installation of the PRDwSF onto the lid of the RNS waste containers, there are no additional changes necessary to facility structures, systems, and components to perform the activities described above.

### 3.6 Readiness Determination

In accordance with FSD-115-001, Verification of Readiness to Start Up or Restart LANL Nuclear Facilities, Activities, and Operations, this activity was determined not to require formal readiness. There will be a Management Self-Assessment (MSA) for PRDwSF installation. The MSA will be performed in accordance with FSD-115-002, Verification of Readiness to Start Up or Restart LANL Nuclear Facilities, Activities, and Operations. There will be a Facility Operations Director-directed Management and Observation Verification for PRDwSF installation on POCs.

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#### 4. REFERENCES

AREAG-PLAN-1373, TA-54 Area G Implementation Plan for AREAG-ESS-14-002, Revision 6.1

AREAG-WO-DOP-1340, TA-54 Area G Remediated Nitrate Salt SWB Lid Removal

AREAG-WO-DOP-1369, TA-54 Area G RNS POC PRDwSF Installation

AREAG-WO-DOP-1343, TA-54 Area G Remediated Nitrate Salt Container PRDwSF Installation

AREAG-WO-DOP-1347, Assembly of PRDwSF

CSLA-13-064, TA-54 Area G, 55-Gallon Drum Criticality Safety Requirements for General Storage Areas

CAL-99-MULT-01257, Drum POC Lid Vent Flowrate Evaluation

EM2016-5185R2, Justification for Not Incorporating the Pressure Relief Device with Supplemental filtration (PRDwSF) to Nitrate Salt Bearing Waste Containers Processed with Waste Lock 770<sup>®</sup>

EM2016-5070, Technical Basis for the Addition of a Safety Class Pressure Relief Device, Supplemental Filtration, and Choice of Operational Temperature for Addition of the System

EP-AREAG-SO-1372, TA-54-Area G Operating Requirements

FSD-115-001, Verification of Readiness to Start Up or Restart LANL Nuclear Facilities, Activities, and Operations

LANL Nitrate Salt-Bearing Waste Container Isolation Plan, Revision 6, May 2016, LA-UR 16-22832

LANL Nitrate Salt-Bearing Waste Container Isolation Plan, Revision 7, September 2016, LA-UR 16-26708

Los Alamos National Laboratory Hazardous Waste Facility Permit, November 2010, attachments, and all revisions

NCS-CSED-16-031, Criticality Safety Evaluation for PRDwSF Installation in RNS-bearing Drums in Dome 375 at TA-54

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# 4. REFERENCES (continued)

NCS-CSED-16-046, Criticality Safety Evaluation for the Replacement of Lids on RNS-bearing Drums in Dome 375 at TA-54

NCS-CSED-16-015, Criticality Safety Evaluation for Opening Overpacks Containing RNS-bearing Drums in Dome 375 at TA-54.

NCS-CSED-16-053, Criticality Safety Evaluation for PRDwSF Installation in RNS-bearing POC Drums in Dome 375 at TA-54.

Safety Evaluation Report, SER-AREA G-ESS-14-002, Revision 5.0, November 2016, Approving Evaluation of the Safety of the Situation, AREAG-ESS-14-002-R6. l, Titled "PISA-Transuranic Waste Drums Containing Treated Nitrate Salts MayChallenge the Safety Analysis"

Safety of the Situation (ESS) AREAG-ESS-14-002, Potential Inadequacy of the Safety Analysis (PISA) – TRU Waste Drums Containing Treated Nitrate Salts May Challenge the Safety Analysis (ESS-14-002)

LA-CP-16-20038, Drum Scale Testing of the Thermolytic Response of a Remediated Nitrate Salts (RNS) Surrogate Waste Mixture

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#### **APPENDIX A**

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Justification for Not Incorporating the Pressure Relief Device with Supplemental Filtration (PRDwSF) to Nitrate Salt Bearing Waste Containers Processed with WastLock® 770



AD Environmental Management

To: Derek Gordon, ADNHHO
From: David Funk, ADEM DE

Phone: 505-667-9659 Symbol: EM2016-5185R2 Date: August 3, 2016

Subject: Justification for Not Incorporating the Pressure Relief Device with Supplemental Filtration (PRDwSF) to Nitrate Salt Bearing Waste Containers Processed with Waste Lock® 770

The Remediated Nitrate Salt (RNS) population includes a subpopulation of four nitrate salt bearing waste containers (Pipe Overpack Containers – POCs) containing waste that was processed with Waste Lock® 770 (in 2010). Waste Lock® 770 is an engineered polymer designed to absorb significant quantities of aqueous liquids, but is only effective when sorbing neutral pH and relatively low ionic strength (low salt content) liquids. In addition, while it can be nitrated, the conditions are extremely severe (high acid concentration and increased temperature)¹ and it is not expected to exhibit the same thermal sensitivity as the salts that were processed with sWheat pet litter. Furthermore, since the material is contained in POCs, the quantity (mass of material) is significantly less than that available in 55-gallon drums, making the likelihood of runaway reduced, primarily due to the smaller amount of potentially reactive material. Thus, the material processed with Waste Lock® is not expected to exhibit thermal runaway. To support this assertion, we evaluated the material for the hazardous characteristic of ignitability (D001 testing) and conducted small-scale thermal testing (APTAC). The results of the work support our conclusion and include:

- Evaluation of Unremediated Nitrate Salt (UNS) surrogate absorbed with Waste Lock® did not yield an ignitable (oxidizing) material.
- Small-scale Automatic Pressure Tracking Adiabatic Calorimetry (APTAC) tests show
  thermal onset temperatures greater than 165 °C, which is over 120 °C higher than the
  salt/Swheat surrogate that was developed<sup>2</sup> and used to evaluate the proposed treatment to
  eliminate the hazardous characteristic of ignitability.<sup>3</sup> Assuming a 2 x increase in reactivity
  per 10 °C, the Waste Lock® material would be ~4000 times less reactive than this
  surrogate at room temperature.

Additional details discussing these results are found below.

#### The Waste Lock® POC Characteristics - a brief history

The four POCs processed with Waste Lock® 770 were the first of the legacy nitrate salts to have been processed at WCRRF, and were in fact, a surprise to operations as the parent containers had been categorized as debris. They were also of high activity, which led to the use of POCs that provide shielding for the packaged waste. The records of the processing, as most from WCRRF of that time, are inadequate,

<sup>&</sup>lt;sup>3</sup> K. Anast and D. J. Funk, "Summary Report of Laboratory Testing to Establish the Effectiveness of Proposed Treatment Methods for Unremediated and Remediated Nitrate Salt Waste Streams," LA-UR-16-22658 (2016).



Phil Leonard, M-7, private communication.

<sup>&</sup>lt;sup>2</sup> Brown, "PLAN-TA9-2443(U), Rev. B Remediated Nitrate Salt (RNS) Surrogate Formulation and Testing Standard Procedure," LA-UR-16-21746 and the results found in M7-16-6063, Memorandum, Summary of Remediated Nitrate Salt Surrogate Formulation and Testing, TO: David J. Funk, ADEP, FROM: Geoffrey Brown, M-7, dated May 3, 2016

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and while it is likely that only the liquids were absorbed with the Waste Lock®, it is possible that the solid salts were also mixed with absorbent material. Follow on Real Time Radiography (for WIPP certification) demonstrated that the Waste Lock® was ineffective at sorbing the liquids (the material dewatered). Operations discussed the results with the manufacturer of Waste Lock® who indicated the issue with trying to use Waste Lock® with low pH and high ionic strength liquids: Waste Lock® 770 is not effective under those conditions and the manufacturer was not surprised by the result of dewatering. After RTR, the processed material was returned to storage, and during the extent of condition review to evaluate and isolate the full population of nitrate salt bearing waste containers, these four containers were identified, transferred into storage within the 54-0375 Perm-Con®, and added to the RNS population.

#### Surrogate choice

Due to the poor records, it is unclear as to the quantities of Waste Lock® that were added to the nitrate salt solids and liquids. However, the "recipe" in use at the time, was one cup of absorbent per gallon of liquid, and our previous small scale testing² has demonstrated that the thermal sensitivity increases as the ratio of salt to fuel increases (more oxidizer, more sensitive; materials that are very fuel rich become unreactive – not enough oxidizer present). In addition, we have evaluated the effectiveness of the addition of zeolite to eliminate the hazardous characteristic of ignitability and corrosivity using EPA and UN DOT testing guidance.³ Testing demonstrated that the dewatered liquid itself was not oxidizing (see Table 2), providing some confidence that the material is not ignitable. However, to ensure confidence that the material does not present an ignitable hazard, we have evaluated additional surrogates thermal sensitivity, using the following materials:

Table 1. Surrogates used with Waste Lock®

1:1 Fuel to Oxidizer (mass percent)	Saturated Nitrate Salts/1M Acid Absorbed with Waste Lock® (mass percent)
46% WB8 Salt;	25% NaNO <sub>3;</sub>
4% Pb(NO <sub>3</sub> ) <sub>3</sub> ;	37.5% 1M Nitric Acid;
50% Waste Lock®	37.5% Waste Lock®
	Oxidizer (mass percent)  46% WB8 Salt;  4% Pb(NO <sub>3</sub> ) <sub>3</sub> ;

The last mixture was chosen to represent a potentially greater oxidizing liquid than the saturated liquid that was initially used to evaluate treatment effectiveness, which does not exhibit oxidizing properties itself.<sup>3</sup> The United Nations "Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria" indicate that 45 wt. % NaNO<sub>3</sub> solution is oxidizing (Packing Group III).<sup>4</sup> This solution was chosen to represent a greater oxidizing material than NaNO<sub>3</sub> alone, through addition of the acid. This also lowers the pH, thereby rendering the Waste Lock® ineffective at absorbing the liquid (low pH and high ionic strength).

<sup>&</sup>lt;sup>4</sup> United Nations, "Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria", United Nations, Fifth revised edition, United Nations, New York and Geneva (2009).

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#### Testing to Evaluate Ignitability

As noted above, Southwest Research Institute (SwRI), a certified EPA laboratory, was contracted to provide qualified personnel, equipment, materials, and facilities to formulate and analyze waste surrogates. This effort included formulating surrogate nitrate salts, preparing nitrate salt solutions, and blending the nitrated salts or solutions with Waste Lock® 770. Unremediated Nitrate Salt (UNS) surrogates using the salt mixture identified in [3] were mixed with Waste Lock and UN DOT 0.2 test was conducted to evaluate the liquid as an oxidizer. As the waste that was placed into the POCs, the liquid was not able to be fully absorbed, due to the high ionic strength, and low pH. A description of the test and results follow. For these test, the standard recipe that was in place at the time the waste was processed (1 cup Waste Lock® to 1 gallon liquid or 16:1 liquid: Waste Lock®), was utilized.

#### UN DOT 0.2 Test: Test for Oxidizing Liquids

UN DOT 0.2 is designed to measure the potential for a liquid substance to increase the burning rate or burning intensity of a combustible substance when the two are thoroughly mixed or to form a mixture that spontaneously ignites. The liquid is mixed in a 1:1 ratio by mass with fibrous cellulose and heated in a pressure vessel while the rate of pressure rise is determined. If the rate exceeds a prescribed standard, it is categorized as an oxidizer.

#### Results

Table 2. Oxidizer Test results using WB8 absorbed with Waste Lock® 770.

Blend ID	UNS Blend Formulation		Test Results
	UNS Sol (mL)	Waste Lock® 770 (mL)	UN O.2 Testing
UNS Blend 14	50	3.12	Not Div 5.1

As indicated above, the saturated liquid after absorption with Waste Lock®, dewaters, and the remaining liquid does not exhibit the hazardous characteristic of ignitability: it is not oxidizing.

#### Automatic Pressure Tracking Adiabatic Calorimetry (APTAC) Testing

APTAC is a measurement that determines the temperature at which a material begins to self-heat and the instrument monitors the thermal and pressure behavior of that material during the self-heating process. In this test, several grams of material are loaded into a titanium sample bomb that is mounted inside a furnace. The bomb is instrumented with a pressure line and thermocouple that is inserted into the sample. In a typical experiment, the sample is heated in 2 °C steps and the temperature is monitored at each step for some tens of minutes. If there is no indication of self-heating, the next step is taken. If the sample does begin to self-heat, the instrument switches to its tracking mode and ramps the furnace at the same rate that the sample is self-heating. This produces adiabatic conditions – the sample cannot lose heat to the surroundings. The heating stops when the heating rate exceeds the limit of the instrument, the pressure exceeds limits, or the sample temperature exceeds a predetermined threshold. The onset temperature of the self-heating is an important metric for ranking materials relative to one another in terms of thermal

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stability. The adiabatic nature of the measurement makes this more relevant to larger masses whose thermal conductivity may inhibit heat loss from a hot spot.

Shown in Table 3 below, are the results of the testing using Waste Lock®, along with results from the same surrogates that were absorbed with sWheat. As can be seen in the table, the sWheat based formulations exhibit much greater thermal sensitivity (lower self-heating onset temperatures) than do the Waste Lock® formulations. This is ascribed to differences related to the ability of the material to be nitrated and its overall reactivity. As we have demonstrated previously, the salt matrix generates an oxidizing atmosphere leading to nitration of the sWheat increasing its overall thermal sensitivity, which is not expected to occur with Waste Lock®.

Table 3. Comparison of the self-heating onset temperatures of the formulations created with sWheat and those created with Waste Lock® 770.

Formulation	First Test Onset Temperature (°C)	Second Test Onset Temperature (°C)
15% sWheat, 4% Pb, and balance WB8 (SFWB8-15-4)	42	48
35% sWheat, 4% Pb, and balance WB8 (SFWB8-35-4)	64	58
15% Wastelock, 4% Pb and balance WB8 (WL-15-4)	170	168
50% Wastelock, 4% Pb and balance WB8 (WL-50-4)	222	213
Saturated NaNO <sub>3</sub> and nitric acid (Sat-WL)	208	208

Finally, while comparisons over many decades of temperature are not readily accomplished, the APTAC data can be used to provide kinetic parameters for the initial thermal response. The temperature profiles are fit to a simple Arrhenius form and we have then calculated the rate constants at room temperature, for the most thermally sensitive formulation, and the Waste Lock® formulations. As can be seen in Table 4, there is a difference in reactivity between these two formulations that is approximately a factor of one thousand. Thus, the Waste Lock® formulated materials ability to self-heat and runaway can be appropriately categorized as Beyond Extremely Unlikely (BEU), when comparing with the most sensitive sWheat based materials.

Table 4. Comparison of rate constants for the sWheat and Waste Lock® based formulations at 75°F.

Data Set	Prefactor (log (1/s))	Activation Energy (kJ/mol)	Rate Constant at 24.89 °C (75 °F, 298.04 K) s <sup>-1</sup>
SFWB8-15-4	4.5	63	2.87E-07
SFWB8-15-4	11.1	106	3.32E-08
SFWB8-15-4	7.1	77	4.02E-07
WL-15-4	3.96	75.8	4.73E-10

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WL-15-4	2.26	67.5	2.69E-10
WL-50-4	10.2	145.9	4.25E-16
WL-50-4	7.8	120	5.86E-14
Sat-WL	10.5	146.6	6.40E-16

DJF:as

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Jim O'Neil, LASO-O-NS Mark Kobi, OS-BSI Sharon Walker, SB-WATS Karen McHugh, SB-WATS Dave Frederici, WD-WPE Kurt Anast, WD-WPE Wayne Hohs, WD-DO

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#### **APPENDIX B**

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#### **Individual Waste Stream Descriptions**

#### **LA-CIN01 Waste Stream Description:**

Waste stream LA-CIN01.001 consists primarily of inorganic homogeneous solid waste (cemented transuranic waste) generated in TA-55. The waste includes materials encased in Portland or gypsum cement such as aqueous and organic liquids from the six operational areas (e.g., nitrate operations), ash, calcium chloride salts, chloride solutions, evaporator bottoms and salts, filter aid, filter cakes (e.g., hydroxide cake), plutonium/uranium filings and fines, glovebox sweepings, graphite powder, HEPA filter media, leached ash residues, leached particulate solids (e.g., ash, sand, slag, and crucible parts), oxides (e.g., americium, metal, and uranium), miscellaneous oils (e.g., pump oil), silica solids, solvents, spent ion exchange resins, trioctyl phosphineoxide and iodine in kerosene, and uranium solutions. A small fraction of debris waste (less than 50 percent by volume) including plastic packaging, metal packaging, and personal protective equipment (PPE) (e.g., leaded gloves) may also be present. Finally, some secondary waste generated during remediation/repackaging operations may be added to the waste containers, including but not limited to: absorbent (e.g., Waste Lock 770 [sodium polyacrylate]), alkaline batteries, Fantastik bottles used during decontamination, miscellaneous hand tools, paper/plastic tags and labels, plastic/metal wire ties, PPE, plastic sheeting used for contamination control, rags and wipes (Kimwipes), and original packaging material (e.g., metal, plastic bags, plywood sheathing, rigid liner lids cut into pieces).

On a waste stream basis, the two predominant isotopes by mass for waste stream LA-CIN01.001 are plutonium (Pu)-239 and uranium (U)-238 and over 95 percent of the total activity is from americium (Am)-241, Pu-238, Pu-239, and Pu-241.

#### **LA-MHD01** Waste Stream Description:

Waste stream LA-MHD01.001 consists of mixed heterogeneous debris waste generated in TA-55. The debris waste includes paper, rags, plastic, rubber, wood-based HEPA filters, other plastic-based and cellulose-based items (e.g., PPE), noncombustible items (e.g., metal and glass), and lesser quantities of homogeneous solids (less than 50 percent by volume) contaminated with nuclear materials (e.g., americium oxide). Plastic-based waste includes (but may not be limited to): bottles, dry-box gloves (unleaded neoprene base), gloves including leaded gloves, ion-exchange resins, Plexiglas, polyethylene and vinyl, polystyrene, polyvinyl chloride plastic, tape, Tygon tubing, and vials. Rubber- and Teflon-based waste includes rubber gloves, Teflon tape, gaskets, and stoppers. Cellulose-based waste includes (but may not be limited to): booties, cardboard, cotton gloves, coveralls, laboratory coats, paper, rags, wood, and similar materials. Noncombustible debris waste includes (but may not be limited to): bottles (e.g., glass and metal), cans (e.g., steel and brass), composite HEPA filters, crucibles, equipment (e.g., furnaces, foundry parts, machine tools and parts), fluorescent bulbs, glass, gloveboxes, glovebox

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#### **Individual Waste Stream Descriptions (continued)**

windows, graphite, lead (e.g., shielding), metal pipes, miscellaneous labware, metal (e.g., beryllium), motors, pumps, slag, small tools, and ventilation ductwork.

Homogeneous solid waste (less than 50 percent by volume) includes: hydroxide cake/filter materials, salts, and ash residues. Hydroxide cake/filter materials are composed of precipitated materials such as americium, cadmium, calcium, chromium, iron, lead, magnesium, mercury, neptunium, plutonium, potassium, silver, sodium hydroxide, thorium, and uranium.

Salt waste can include varying mixtures of calcium chloride, cesium chloride, lithium chloride, magnesium chloride, potassium chloride, sodium chloride, zinc chloride, residual entrained calcium and zinc metal, and various plutonium and americium compounds. Ash residues originate from the thermal reduction of organic-based waste products that were contaminated with plutonium (e.g., plastics, rubber, wood, cellulosics, and oils) and may include incomplete combustion products such as small pieces of plastic and metal debris items. The waste stream also includes a small fraction of liquids (e.g., waste oils and organics) and solids (e.g., nitrate salts) absorbed or mixed with absorbent materials which may include Ascarite II (sodium hydroxide coated silicate), diatomaceous earth (silica and quartz), kitty litter (clay), vermiculite (hydrated magnesium-aluminum-iron silicate), and/or zeolite (aluminosilicate mineral). Finally, some secondary waste generated during remediation/repackaging operations may be added to the waste containers including but not limited to: absorbent (e.g., Waste Lock 770 [sodium polyacrylate]), alkaline batteries, Fantastik bottles used during decontamination, miscellaneous hand tools, paper/plastic tags and labels, plastic/metal wire ties, PPE, plastic sheeting used for contamination control, rags and wipes (Kimwipes), and original packaging material (e.g., metal, plastic bags, plywood sheathing, rigid liner lids cut into pieces).

On a waste stream basis, the two predominant isotopes by mass for waste stream LA-MHD01.001 are Pu-239 and U-238 and over 95 percent of the total activity is from Pu-238, Pu-239, and Pu-241.

#### **LA-MIN02** Waste Stream Description:

Waste stream LA-MIN02-V.001 consists primarily of inorganic particulate waste generated in TA-55. The waste is largely comprised of transuranic waste such as liquids and solids absorbed or mixed with absorbent (e.g., Ascarite II [sodium hydroxide coated silicate], diatomaceous earth [silica and quartz], kitty litter [clay], vermiculite [hydrated magnesium-aluminum-iron silicate], and/or zeolite [aluminosilicate mineral]). Examples of absorbed liquids include acids (e.g., hydrochloric acid, hydrofluoric acid, and nitric acid); carbon tetrachloride; ethylene glycol; kerosene; methanol; methylene

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#### **Individual Waste Stream Descriptions (continued)**

chloride; silicone based liquids (e.g., silicone oil); tetrachloroethylene; tributyl phosphate; trichloroethylene; and various types of oils including hydraulic, vacuum pump, grinding, and lapping (mixture of mineral oil and lard). Solids mixed with absorbents are typically evaporator salts (i.e., nitrate salts).

The waste is also expected to contain heavy metals such as cadmium, chromium, and lead. Liquids and solids not absorbed or mixed with absorbent are often cemented and disposed of separately in waste stream LA-CIN01.001. A small fraction of debris waste (less than 50 percent by volume), including plastic packaging, metal packaging, lead (e.g., shielding), PPE, and metal fines, may also be present. Finally, some secondary waste generated during remediation/repackaging operations may be added to the waste containers, including but not limited to: absorbent (e.g., Waste Lock 770 [sodium polyacrylate]), alkaline batteries, Fantastik bottles used during decontamination, miscellaneous hand tools, paper/plastic tags and labels, plastic/metal wire ties, PPE, plastic sheeting used for contamination control, rags and wipes (Kimwipes), and original packaging material (e.g., metal, plastic bags, plywood sheathing, rigid liner lids cut into pieces).

On a waste stream basis, the two predominant isotopes by mass for waste stream LA-MIN02-V.001 are Pu-239 and U-238 while over 95 percent of the total activity is from Pu-239, Pu-240, and Pu-241.

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#### **Individual Waste Container Values**

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PKG ID	Parent ID	Overpack ID	Ctr. Type	Gross Wt (lbs)	FGE	TOTAL DOSE (mR/hr)	PECi	EC PECi	Waste Stream
68408	S842463	SB02198	SWB-55	205.2	18.95	10.5	4.26	3.75	LA-MHD01.001
68430	S833846	RNSOP68430	SWB-POC	382.80	33.11	1.5	11.23	11.23	LA-MIN02-V.001
68507	S853279	RNSOP68507	SWB-POC	353.10	36.60	0.9	4.77	4.77	LA-MIN02-V.001
68540	S842181	70503	SWB-55	85	0.38	13.5	0.30	0.26	LA-MHD01.001
68553	S842181	70503	SWB-55	118.20	2.78	33.5	1.87	1.64	LA-MHD01.001
68567	S816837		SWB-55	202.00	4.62	7.5	1.31	1.31	LA-MHD01.001
68624	S824184		SWB-55	152.00	10.61	38.5	0.95	0.95	LA-MIN02-V.001
68631	S825810		SWB-55	214.00	2.26	70.5	1.52	1.52	LA-MIN02-V.001
68638	S825810		SWB-55	85.00	0.55	14.5	0.41	0.41	LA-MHD01.001
68648	S855139	SB50442	SWB-55	268.6	62.37	28	16.70	14.69	LA-MIN02-V.001
68665	S853492	SB50529	SWB-55	371.8	47.11	17.5	10.10	8.89	LA-MIN02-V.001
68685	S855793		SWB-55	391.00	21.94	26.7	8.54	8.54	LA-MIN02-V.001
69013	S870213	RNSOP69013	SWB-POC	348.70	3.56	1.5	0.67	0.67	LA-MIN02-V.001
69015	S851418	RNSOP69015	SWB-POC	357.5	9.27	1.5	3.01	3.01	LA-MIN02-V.001
69036	S873554		SWB-55	175.00	22.05	31.3	10.31	10.31	LA-MHD01.001
69076	S852530	SB50452	SWB-55	384	56.00	60.8	9.97	8.77	LA-MIN02-V.001
69079	S901114	SB50073	SWB-55	401.8	58.33	70.5	21.09	18.56	LA-MIN02-V.001
69183	S870478	SB50443	SWB-55	427	46.81	50.5	15.07	13.26	LA-MIN02-V.001
69208	S851772	SB50069	SWB-55	507.2	157.36	82	39.12	34.42	LA-MIN02-V.001
69280	S841251	SB50431	SWB-55	236.2	69.35	22.8	18.06	15.89	LA-MIN02-V.001
69298	S841251		SWB-55	448.00	122.44	46.5	23.18	23.18	LA-MIN02-V.001
69361	S892963	SB50451	SWB-55	170	17.34	30.5	4.94	4.34	LA-MIN02-V.001
69445	S823229		SWB-55	366.00	57.59	31	5.15	5.15	LA-MIN02-V.001
69490	S892963	SB50522	SWB-55	371	75.98	60.5	18.90	16.63	LA-MIN02-V.001
69491	S891387	SB50448	SWB-55	329.8	14.36	60.5	12.06	10.61	LA-MIN02-V.001
69519	S816768	RNSOP69519	SWB-POC	415.80	18.70	2.1	17.19	17.19	LA-MIN02-V.001
69520	S813471	RNSOP69520	SWB-POC	344.30	2.08	2.0	5.09	5.09	LA-MIN02-V.001
69548	S851416		SWB-55	207.00	2.37	7.5	0.94	0.94	LA-MIN02-V.001
69553	S841627		SWB-55	227.00	61.67	29	12.47	12.47	LA-MIN02-V.001
69559	S832148		SWB-55	367.00	22.39	60.5	14.02	14.02	LA-MIN02-V.001
69568	S825664		SWB-55	248.00	5.18	10.5	4.52	4.52	LA-MHD01.001
69595	S852588	SB50418	SWB-55	188.8	57.27	14.5	8.84	7.69	LA-MIN02-V.001
69598	S793450	RNSOP69598	SWB-POC	348.70	0.29	1.5	2.04	2.04	LA-MIN02-V.001
69604	S816768	RNSOP69604	SWB-POC	412.50	4.33	1.6	11.57	11.57	LA-MIN02-V.001

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## **Individual Waste Container Values**

PKG ID	Parent ID	Overpack ID	Ctr. Type	Gross Wt (lbs) 55-gal Ctr.	FGE	TOTAL DOSE (mR/hr)	PECi	EC PECi	Waste Stream
69615	S843673		SWB-55	285.00	85.61	60.9	13.30	13.30	LA-MIN02-V.001
69616	S841627		SWB-55	437.00	62.14	35.5	9.75	9.75	LA-MIN02-V.001
69618	S818412		SWB-55	373.00	3.63	20.5	4.13	4.13	LA-MIN02-V.001
69620	S816768		SWB-55	376.00	9.09	51.3	20.42	20.42	LA-MIN02-V.001
69630	S843672		SWB-55	437.00	74.20	28.6	20.43	20.43	LA-MIN02-V.001
69633	S851418		SWB-55	417.00	59.01	36.5	20.18	20.18	LA-MIN02-V.001
69634	S851416		SWB-55	501.00	35.15	25.5	10.96	10.96	LA-MIN02-V.001
69635	S851418		SWB-55	240.00	17.34	40.5	4.38	4.38	LA-MIN02-V.001
69636	S843672		SWB-55	209.00	50.22	16.8	15.07	15.07	LA-MIN02-V.001
69637	S813471		SWB-55	301.00	5.18	26.5	6.69	6.69	LA-MIN02-V.001
69638	S822679		SWB-55	331.00	5.89	43.5	8.11	8.11	LA-MIN02-V.001
69639	S843673		SWB-55	362.00	31.54	8.5	4.42	4.42	LA-MIN02-V.001
69641	S813471		SWB-55	323.00	5.08	75.5	9.11	9.11	LA-MIN02-V.001
69642	S818412		SWB-55	215.00	3.28	14.5	4.91	4.91	LA-MIN02-V.001
69644	S793450		SWB-55	510.00	4.21	30.5	9.32	9.32	LA-MIN02-V.001
69645	S822679		SWB-55	352.00	17.24	22.5	16.09	16.09	LA-MIN02-V.001
92459	S910171	SB50559	SWB-55	247.2	9.62	30	2.01	0.50	LA-MIN02-V.001
92472	S910171	SB50559	SWB-55	228.00	11.92	50.3	3.27	2.84	LA-MHD01.001
92669	S823187	SB02203	SWB-55	250.00	8.63	12.3	2.04	1.77	LA-MHD01.001
93605	S824541		SWB-55	348.00	21.26	50.7	14.76	14.76	LA-MIN02-V.001
94068	S851852		SWB-55	398.00	173.19	81.3	28.98	28.98	LA-CIN01.001- Cans
94227	S813475		SWB-55	208.00	3.52	11.7	1.30	1.30	LA-MHD01.001

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PKG ID	RTR Date	RTR BDR Results (RTR Operator comments)	2 in. Bung	Inches to Bag	Inches to Waste	Batch Data Report	%FILL (Vol)	%DEBRIS (Vol)	%HOM (Vol)	Iron- based Metal (kg)	Other Metals (kg)	Cellulose (kg)	Rubber (kg)	Plastics (waste materials) XPM (kg)	Inorganic Matrix (kg)
68408	12/12/13	scrap lead, plastic bags, homogeneous solids (liner with lid; fiberboard liner; 2 LOC)	Yes	6	12	LA-RTR2- 13-0135	50	60	40		25.0			6.0	29.1
68430	11/19/13	Plastic bag, homogeneous solids (plastic liner bag; fiberboard liner; 90-mil liner; bottom is dry)	No	6	12	LA-RTR2- 13-0130	70	5	95					2.0	26.9
68507	12/12/13	Plastic bag, homogeneous solids (plastic liner bag; fiberboard liner; rigid liner; bottom is dry; 2 LOC)	No	6	13	LA-RTR2- 13-0132	50	5	95					2.0	13.4
68540	1/13/14	scrap lead, leather gloves, plastic sheeting, homogeneous solids (liner bag; fiberboard liner; 1 LOC)	Yes	8	24	LA-RTR2- 14-0004	20	85	15		0.1	3.0		1.0	1.0
68553	1/9/14	scrap metal, scrap lead, plastic bag, plastic lid, homogeneous solids (bottom is dry)	yes	6	18	LA-RTR2- 14-0003	45	50	50	1.0	0.2			6.0	13.8
68567	1/13/14	scrap lead, leaded rubber glove, plastic bags, homogeneous solids (plastic liner bag; bottom is dry; 1 LOC)	Yes	8	20	LA- HERTR- 14-0004	40	65	35	0.0	31.6		5.0	2.0	20.0
68624	11/14/13	rubber gloves, plastic bags, plastic lid, homogeneous solids (fiberboard liner; bottom is dry; 1 LOC)	Yes	6	18	LA-RTR2- 13-0128	40	25	75				2.0	5.0	28.6
68631	12/9/14	scrap lead, plastic bags, homogeneous solids (plastic liner; fiberboard liner; <u>~20 mL</u> <u>liquid on plastic fold</u> ; bottom is dry)	Yes	6	18	LA-RTR2- 13-0134	45	15	85		20.0			3.0	40.6

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68638	1/9/14	plastic bags, plastic lid, homogeneous solids (plastic liner bags; fiberboard liner)	Yes	4	20	LA-RTR2- 14-0003	25	90	10	(%)	(Ng)	(148)	(Ng)	4.0	1.1
68648	1/15/14	scrap lead, leather gloves, plastic bags, homogeneous solids (plastic liner bags; fiberboard liner; bottom is dry; 2 LOC)	Yes	4	14	LA-RTR2- 14-0005	55	15	85		23.0	1.5		4.0	60.1
68665	11/21/13	scrap lead, leather gloves, plastic bags, homogeneous solids (plastic liner bags; rubber gloves; fiberboard liner; bottom is dry; 2 LOC)	Yes	0	6	LA-RTR2- 13-0131	85	15	85		13.0	1.0		6.0	115.6
68685	12/13/13	scrap metal, scrap lead, plastic bags, homogeneous solids (plastic liner; fiberboard liner; bottom is dry; 2 LOC)	Yes	0	4	LA-HERTR- 13-0121	85	20	80	0.2	25.0			6.0	112.9
69013	3/6/14	plastic bag, homogeneous solids (vented; plastic liner bags; 90- mil rigid liner; fiberboard liner; bottom is dry; 2 LOC)	No	6	18	LA-RTR2- 14-0027	50	5	95					2.0	11.4
69015	4/25/14	scrap (lead) metal, plastic bags, homogeneous solids (vented; 90-mil rigid liner; fiberboard liner; bottom is dry; 2 LOC)	No	8	12	LA-RTR2- 14-0040	60	5	95	0.5				4.0	12.9
69036	1/29/14	scrap lead, leather gloves, plastic bags, homogeneous solids (~10 mL total liquids on the folds of plastic bags; plastic liner bags; fiberboard liner; 2 LOC)	??	6	14	LA-RTR2- 14-0012	50	80	20		33.4	0.2		4.0	8.5

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69076	1/6/14	scrap metal, plastic bags, plastic liner lid, homogeneous solids (90-mil plastic liner lid; plastic liner bag; fiberboard liner; 2 LOC)	Yes	0	0	LA-RTR2- 14-0002	100	5	95	5.0				6.0	130.1
69079	1/16/14	pipe cutter, scrap lead, tape roll, plastic bags, homogeneous solids (fiberboard liner; bottom is dry; 2 LOC)	Yes	0	6	LA-RTR2- 14-0006	75	10	90	3.5	4.3	0.1		6.0	134.7
69183	1/16/14	scrap lead, leather gloves, plastic bags, 90 mil liner lid, homogeneous solids (plastic liner; bottom is dry; 2 LOC)	Yes	0	0	LA-RTR2- 14-0006	100	10	90		3.0	4.0		8.0	145.1
69208	1/16/14	scrap metal, scrap lead, plastic bags, 90 mil liner lid, homogeneous solids (plastic liner; fiberboard liner; bottom is dry; 2 LOC)	Yes	0	3	LA-HERTR- 14-0006	95	10	90	2.0	8.0			2.0	184.1
69280	1/30/14	scrap lead, plastic bags, homogeneous solids (plastic liner; fiberboard liner; bottom is dry)	Yes	6	18	LA-RTR2- 14-0013	40	15	85		6.0			4.0	64.6
69298	1/30/14	scrap lead, tape roll, plastic bags, plastic lid, homogeneous solids (plastic liner; fiberboard liner; ~10 mL each of liquid on the fold of 2 plastic bags; bottom is dry; 2 LOC)	Yes	0	0	LA-RTR2- 14-0013	95	10	90		5.0	0.1		4.0	160.5
69361	3/6/14	hardware, plastic bag, homogeneous solids (liner bag; bottom is dry; 2 LOC)	Yes	6	18	LA-RTR2- 14-0027	35	5	95	0.1				2.0	41.5

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69445	3/6/14	scrap lead, plastic bags, homogeneous solids (liner bag; fiberboard liner; bottom is dry; 2 LOC)	Yes	6	6	LA-RTR2- 14-0027	75	15	85		15.0			6.0	110.6
69490	3/6/14	scrap lead, leather gloves, plastic bags, 90 mil liner lid, homogeneous solids (fiberboard liner; bottom is dry; 2 LOC)	Yes	0	0	LA-HERTR- 14-0030	95	5	95		3.0	0.4		8.0	123.2
69491	3/6/14	hardware, scrap lead, liner lid, plastic bag, homogeneous solids (liner bag; fiberboard liner; bottom is dry, 2 LOC)	Yes	0	3	LA-RTR2- 14-0027	85	5	95	0.1	5.0			6.0	105.0
69519	4/28/14	scrap lead, homogeneous solids (plastic liner; plastic bags; bottom is dry; 1 LOC)	No	6	7	LA-RTR2- 14-0041	75	5	95		7.0				36.9
69520	4/25/14	plastic bags, homogeneous solids (vented; 90-mil liner; liner bag; liner is vented; fiberboard packing material; bottom is dry; 2 LOC)	No	6	14	LA-RTR2- 14-0040	65	4	60					2.0	9.4
69548	4/30/14	scrap lead, plastic sheeting, plastic bags, homogeneous solids (plastic liner bag; fiberboard liner; 2 LOC)	Yes	8	18	LA-HERTR- 14-0051	40	10	90		23.0			2.0	35.6
69553	4/30/14	scrap lead, plastic sheeting, plastic bags, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 2 LOC)	??	8	16	LA-HERTR- 14-0051	50	10	90		5.0			2.0	62.6
69559	3/27/14	scrap lead, plastic bags, 90 mil plastic liner lid, homogeneous solids (90-mil plastic liner; fiberboard liner; 2 LOC)	Yes	6	10	LA-HERTR- 14-0041	70	5	95		30.0			2.0	100.6

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69568	3/26/14	open 30 gal drum, closure ring, drum lid, metal lid, scrap lead, tape roll, plastic bags, homogenous solids (liner bag; closure ring; fiberboard liner with plastic liner bag; bottom is dry; 2 LOC)	Yes	0	0	LA-RTR2- 14-0037	95	60	40	20.0	20.0	0.1		6.0	33.0
69595	3/31/14	metal hardware, scrap metal, scrap lead, plastic sheeting, plastic bags, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 1 LOC)	Yes	8	16	LA-HERTR- 14-0043	65	20	80	2.0	2.0			3.0	45.1
69598	4/25/14	scrap lead, plastic bags, homogeneous solids (vented; fiberboard liner for POC; bottom is dry; 2 LOC)	No	6	18	LA-RTR2- 14-0040	45	5	95		0.1			2.0	11.3
69604	4/25/14	homogeneous solids (vented; fiberboard liner bag; 90-mil rigid liner; bottom is dry; 1 LOC)	No	6	6	LA-RTR2- 14-0040	95	5	95						42.4
69615	4/23/14	scrap lead, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 1 LOC)	Yes	6	8	LA-RTR2- 14-0039	75	15	85		23.0				73.1
69616	4/30/14	scrap metal, hand tool, scrap lead, plastic bags, plastic liner lid, homogeneous solids (fiberboard liner; bottom is dry; 2 LOC)	Yes	2	4	LA-HERTR- 14-0051	90	10	90	3.0	23.0			3.0	135.6
69618	4/23/14	scrap lead, plastic bags, liner lid, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 2 LOC)	Yes	4	6	LA-HERTR- 14-0049	70	20	80		23.0			7.0	106.1

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69620	4/28/14	scrap lead, plastic bags, plastic liner lid, homogeneous solids (fiberboard liner; bottom is dry; 2LOC)	Yes	4	6	LA-RTR2- 14-0041	90	20	80		23.0			2.0	112.1
69630	4/25/14	scrap lead, plastic bags, liner lid, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 2 LOC)	Yes	0	2	LA-RTR2- 14-0040	95	10	90		5.0			5.0	155.1
69633	4/25/14	scrap lead, plastic bags, homogeneous solids (plastic liner bag; bottom is dry; 2 LOC)	Yes	0	2	LA-RTR2- 14-0040	90	10	90		10.0			4.0	142.1
69634	4/30/14	metal cans with material, scrap lead, scrap metal, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 2 LOC)	Yes	0	2	LA-HERTR- 14-0051	95	5	95	5.0	5.0				183.6
69635	4/25/14	scrap lead, plastic bags, plastic lid, homogeneous solids (small amount of scrap lead; plastic liner bag; liner lid; fiberboard liner; bottom is dry; 2 LOC)	??	6	14	LA-RTR2- 14-0040	60	5	95		0.5			5.0	70.1
69636	4/28/14	scrap lead, leather gloves, plastic sheeting, plastic bags, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 2 LOC)	Yes	6	12	LA-RTR2- 14-0041	65	15	85		5.0	3.0		3.0	50.6
69637	4/25/14	scrap lead, leather gloves, plastic bag, homogeneous solids (fiberboard liner; bottom is dry; 2 LOC)	??	6	6	LA-RTR2- 14-0040	75	20	80		5.0	1.5		2.0	94.6
69638	4/25/14	liner lid, plastic bags, homogeneous solids (liner without lid; liner bag; fiberboard liner; bottom is dry; 2 LOC)	??	6	7	LA-RTR2- 14-0040	70	5	95					5.0	111.6

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69639	4/23/14	scrap lead, plastic bags, liner lid, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 2 LOC)	Yes	0	0	LA-RTR2- 14-0039	95	10	90		15.0			3.0	113.1
69641	4/25/14	drum vent, scrap lead, plastic bags, liner lid, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 2 LOC)	Yes	6	8	LA-RTR2- 14-0040	70	10	90	0.1	15.0			5.0	92.5
69642	4/23/14	scrap lead, homogeneous solids (plastic liner bag; scrap metal; fiberboard liner; bottom is dry; 1 LOC)	??	6	13	LA-RTR2- 14-0039	55	15	85		8.0				56.1
69644	4/25/14	hardware, scrap lead, liner lid, plastic bag, homogeneous solids (liner bag; fiberboard liner; bottom is dry, 2 LOC)	Yes	0	0	LA-RTR2- 14-0040	100	5	95	0.1	8.0			7.0	183.0
69645	4/25/14	scrap lead, plastic bags, homogeneous solids (fiberboard liner; bottom is dry; 2 LOC)	Yes	8	10	LA-HERTR- 14-0050	55	15	85		20.0			6.0	100.6
92459	9/4/13	metal lid, hardware, fiberboard insert sleeve, fiberboard packing material, plastic lid, plastic bags, homogeneous solids (fiberboard liner; bottom is dry; 2 LOC)	Yes	0	2	LA-RTR2- 13-0105	90	30	70	12.0		6.0		6.0	54.6
92472	12/20/13	metal hardware, pipe component lid, fiberboard liner sleeve, packing material, 90 mil liner lid, plastic bags, homogeneous solids (POC lid; fiberboard packaging material; 2 LOC)	Yes	6	6	LA-RTR2- 13-0139	65	60	40	19.5		10.0		6.0	34.6

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92669	1/9/14	hardware, metal lid, scrap lead, fiberboard packing material, fiberboard insert sleeve, leather gloves, plastic bags, homogeneous solids (bottom is dry; 2 LOC)	Yes	2	4	LA-RTR2- 14-0003	85	55	45	25.0	3.0	10.0		6.0	36.1
93605	5/9/13	scrap metal, scrap lead, plastic bags, liner lid, homogeneous solids (plastic liner bag; fiberboard liner; bottom is dry; 1 LOC)	Yes	8	12	LA-HERTR- 13-0052	75	20	80	0.5	10.0			4.0	110.5
94068	8/5/13	scrap metal, scrap lead, plastic bags, plastic lid, homogeneous solids (fiberboard liner with plastic bag for packaging material; bottom is dry; 2 LOC)	Yes	4	8	LA-HERTR- 13-0090	80	15	85	2.0	10.0			4.0	131.1
94227	12/12/13	open 30 gal drum, drum lid, scrap lead, plastic bag, liner lid, homogeneous solids (@18" some homogeneous solids; liner bags; fiberboard liner; bottom is dry; 2 LOC)	Yes	4	16	LA-RTR2- 13-0135	100	75	25	22.0	20.0			3.0	16.1

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68685	Nitrate	LA-MIN02-V.001	1227	0.85	8.5	31.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69013	Nitrate	LA-MIN02-V.001	1185	50	0.7	8.3
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69298	Nitrate	LA-MIN02-V.001	1283	1	23.2	198.8
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69445	Nitrate	LA-MIN02-V.001	1199	1	5.1	57.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69520	Nitrate	LA-MIN02-V.001	1180	65	5.1	3.5
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
69616	Nitrate	LA-MIN02-V.001	1271	1	9.8	113.7
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69618	Nitrate	LA-MIN02-V.001	1209	0.9	4.1	5.2
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69620	Nitrate	LA-MIN02-V.001	1211	1	20.4	12.9
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69636	Nitrate	LA-MIN02-V.001	1045	0.5	15.1	81.0
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
69641	Nitrate	LA-MIN02-V.001	1157	0.75	9.1	7.4
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
68540	Nitrate	LA-MHD01.001	85	0.1	0.3	0.6
68553	Nitrate	LA-MHD01.001	118.2	0.4	1.9	3.3
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
67137	NA	LA-MHD01.001	70.2	-	1.8	19.4
92669	Nitrate	LA-MHD01.001	283	0.9	2.0	11.9
92699	Miscellaneous	LA-MHD01.001	140	-	18.2	218.2
Dunnage 1	-	-	-	-		
54249	NA	LA-CIN01.001-Monoliths Lead-Lined	720	-	12.5	55.1
69208	Nitrate	LA-MIN02-V.001	507.2	1	39.1	240.5
69288	NA	LA-MHD03.001	102.2	-	0.0	0.5
69432	NA	LA-MHD01.001	318.8	-	0.2	1.7
69079	Nitrate	LA-MIN02-V.001	401.8	0.7	21.1	106.3
69184	Cemented	LA-CIN01.001-Cans	425.4	-	17.9	58.8
69297	NA	LA-MHD01.001	270.2	-	2.7	32.3
69443	NA	LA-MHD05-ITRI.001	130	-	0.8	13.8

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54068	NA	LA-CIN01.001-Monoliths Lead-Lined	823	-	23.2	105.4
57353	NA	LA-CIN01.001-Monoliths Lead-Lined	438.4	-	20.4	61.2
69280	Nitrate	LA-MIN02-V.001	236.2	0.3	18.1	114.1
Dunnage 1	-	-	-	-		
57357	NA	LA-CIN01.001-Monoliths Lead-Lined	666.8	-	27.9	95.2
69076	Nitrate	LA-MIN02-V.001	384	1	10.0	97.9
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
57653	NA	LA-CIN01.001-Monoliths Lead-Lined	799	-	23.6	85.8
68799	NA	LA-MIN03-NC.001	461.5	-	0.1	0.6
69271	NA	LA-MIN03-NC.001	333.8	-	0.1	0.6
69490	Nitrate	LA-MIN02-V.001	371	1	18.9	144.0
68567	Nitrate	LA-MHD01.001	1037	0.4	1.3	6.5
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3						

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68624	Nitrate	LA-MIN02-V.001	986	0.6	0.9	10.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
68631	Nitrate	LA-MIN02-V.001	1048	0.6	1.5	3.2
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
68638	Nitrate	LA-MHD01.001	919	0.3	0.4	1.1
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69553	Nitrate	LA-MIN02-V.001	1062	0.4	12.5	99.0
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-					

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69634	Nitrate	LA-MIN02-V.001	1336	1	11.0	69.0
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69635	Nitrate	LA-MIN02-V.001	1075	0.75	4.4	31.5
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69637	Nitrate	LA-MIN02-V.001	1136	1	6.7	7.4
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69638	Nitrate	LA-MIN02-V.001	1166	0.8	8.1	8.7
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
69015	Nitrate	LA-MIN02-V.001	1193	60	3.0	18.2
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69639	Nitrate	LA-MIN02-V.001	1197	0.95	4.4	54.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69642	Nitrate	LA-MIN02-V.001	1050	0.6	4.9	4.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69644	Nitrate	LA-MIN02-V.001	1345	1	9.3	7.1
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
94227	Nitrate	LA-MHD01.001	1049	0.95	1.3	5.3
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
68430	Nitrate	LA-MIN02-V.001	1218.0	70	11.2	81.4
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
68507	Nitrate		1187.00	50	4.8	64.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
68408	Nitrate	LA-MHD01.001	205.2	0.5	4.3	34.1
69017	NA	LA-MHD01.001	197.2	-	19.3	220.2
93915	Cemented	LA-MHD01.001	196.4	-	0.4	4.6
Dunnage 1	-	-	-	-		
68648	Nitrate	LA-MIN02-V.001	268.6	0.6	16.7	116.2
69518	NA	LA-MHD08.001	336.4	-	0.0	0.4
69605	NA	LA-MHD08.001	338.6	-	0.0	0.1
Dunnage 1	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
54016	NA	LA-CIN01.001-Monoliths Lead-Lined	789	-	19.7	132.8
69183	Nitrate	LA-MIN02-V.001	427	1	15.1	89.0
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
59374	NA	LA-MIN02-V.001	137	-	0.7	8.5
92459	Nitrate	LA-MIN02-V.001	247.2	1	2.0	12.7
92472	Nitrate	LA-MHD01.001	103.81	0.95	3.3	16.4
92522	Miscellaneous	LA-MHD01.001	266.4	-	6.0	61.0
69036	Nitrate	LA-MHD01.001	1010	15	10.3	38.1
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69519	Nitrate	LA-MIN02-V.001	1251	75	17.2	47.9
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
69548	Nitrate	LA-MIN02-V.001	1042	50	0.9	3.4
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69559	Nitrate	LA-MIN02-V.001	1201	80	14.0	33.1
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69604	Nitrate	LA-MIN02-V.001	1248	95	11.6	10.9
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69645	Nitrate	LA-MIN02-V.001	1188	70	16.1	36.2
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
93605	Nitrate	LA-MIN02-V.001	1184	0.8	14.8	30.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
94068	Nitrate	LA-CIN01.001-Cans	1233	0.9	29.0	283.7
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		
Dunnage 3	-	-	-	-		
69320	NA	LA-MIN02-V.001	568.8	-	5.2	81.7
69595	Nitrate	LA-MIN02-V.001	188.8	0.6	8.8	73.1
69596	Cemented	LA-CIN01.001-Cans	309	-	14.6	5.1
Dunnage 1	-	-	-	-		
54014	NA	LA-CIN01.001-Monoliths Lead-Lined	809	-	21.9	171.8
69491	Nitrate	LA-MIN02-V.001	329.8	1	12.1	34.6
Dunnage 1	-	-	-	-		
Dunnage 2	-	-	-	-		

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PKG_ID	Salt Type	Waste Stream2	SWB GROSS WT	% Fill	Sum of PECi	Sum of FGE2U
68980	NA	LA-MHD01.001	208	-	1.5	18.8
69361	Nitrate	LA-MIN02-V.001	170	0.65	4.9	24.6
69425	NA	LA-MHD01.001	88.4	-	3.4	0.1
Dunnage 1	-	-	-	-		
68665	Nitrate	LA-MIN02-V.001	371.8	1	10.1	80.0
68866	NA	LA-MHD09.001	177	-	0.0	0.1
68929	NA	LA-MIN03-NC.001	450.04	-	0.1	1.3
69544	NA	LA-MHD08.001	159.4	-	0.0	0.2
					796.7	4589.7

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#### **APPENDIX F**

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To/MS: Derek Gordon, ADNHHO

From/MS: David Funk, ADEM/WD-DO

Phone: 7-9659 Symbol: EM2016-5070 Date: February 29, 2016

Subject: Technical Basis for the Addition of a Safety Class Pressure Relief Device, Supplemental Filtration, and Choice of Operational Temperature for Addition of the System

The Remediated Nitrate Salt (RNS) waste is an ignitable, incompatible waste that is potentially corrosive, and must be treated for removal of the characteristic(s) of ignitability and corrosivity prior to off-site shipment for disposal. To better understand the properties of the waste, LANL developed surrogate nitrate salt mixtures by studying the chemical composition of measured salt solutions from TA-55 processing operations." The analysis utilized software that allows the calculation of the composition of liquid and solids salt fractions using thermodynamic equilibrium principles. These estimates of the solid fractions were utilized to create surrogates of the evaporator bottoms (the solid salts that precipitated during the waste collection phase of the Pu purification processes at TA-55). RNS surrogates were formulated through the addition of sWheat Scoop® pet litter to these salt surrogates and the thermal sensitivity of the RNS surrogates were evaluated using small scale testing that included Differential Scanning Calorimetry (DSC) and Automatic Pressure Tracking Adiabatic Calorimetry (APTAC). vi,vii Testing of these materials demonstrated that the surrogates have low temperature chemical reactions that exhibit exothermic behavior at onset temperatures as low as 42-60° Celsius (as measured using APTAC). viii This supports the hypothesis proposed by Clark and Funk, ix and separately by the Technical Assessment Team, that a series of exothermic reactions, starting at room temperature, could lead to thermal runaway that would heat, pressurize, and breach the drum and ultimately, vent radioactive material. We note that thermal runaway results when exothermic chemical heating cannot be offset by cooling from thermal transport out of the drum (conduction/convection/ radiation), leading to increased chemical reaction rate and eventually, runaway. This fact leads to a control strategy that would utilize reduced temperatures to minimize reactivity. Reduced temperatures will slow reaction rates associated with these chemical processes, and as a result, the likelihood of an exothermic reaction, and importantly, as we note below, decrease the gas production rate. For chemical reactions, as the reaction temperature decreases, the rate of reaction also decreases. This relationship corresponds to a rough approximation that reaction rates decrease by a factor of 2 or 3 for every 10° Celsius lowering in temperature. Hence, temperature is a powerful tool that can be used to control reactivity within the waste.

In addition to these small scale experiments, and at the request of the Accident Investigation Board, Parker et al. designed and conducted a set of full-scale 55-gallon container tests that were performed with surrogate remediated nitrate salt-bearing waste mixtures. The technical objectives of the tests were to develop an understanding of what may have happened to cause the breach of the LANL waste container within the Waste Isolation Pilot Plant, and to help inform decisions for mitigation strategies for the remaining remediated nitrate salt-bearing waste containers. Under the test plan, containers with remediated nitrate salt-bearing waste surrogate mixtures were prepared and monitored for a minimum of eighty-four days for evidence of self-sustained reaction and thermal runaway. In the tests, the independent variables of temperature and pressure were examined. Temperatures of 25° Celsius and 60° Celsius were established as boundary conditions, and containers with both sealed and vented pressure configurations were tested. Details and conclusions of the full-scale 55-gallon container tests are documented in LA-CP-16-20038. The test results show that pressure was crucial to establishing a self-sustained thermal runaway in the tested containers. For the 25 and 60° C sealed experiments, the temperature rise observed in the experiment was directly correlated with a pressure rise, implicating gas phase species in the overall

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chemistry of the runaway. In addition, in both these experiments, the reaction rate slowed when the drum started leaking, presumably due to heat loss (gas escaping) and the decreased reactivity from the loss of gas phase species. Furthermore, in the *vented* 60 °C experiment, the temperature and pressure began accelerating (presumably the gas phase production was overwhelming the NFT filter), at which point the NFT filter failed, allowing the drum to return to ambient pressure. More remarkably, the drums contents had reached a temperature of 115 °C and the temperature rise arrested once the filter failed. This arrest (the contents remained at 115 °C for hours) is assumed to be due to loss of heat (gas escaping) and reduced reactivity due to the loss of gas phase species. These results point to pressure relief and/or an enhanced filtration capability (e.g. higher flow rates) as a means to eliminate the possibility of thermal runaway.

In fact, these results reveal actionable steps that can be taken to improve the safety of the situation for the remediated nitrate salt-bearing waste stored within the TA-54, Area G, Dome 375 PermaCon®. By providing reliable pressure relief, and utilizing cooling as part of a defense-in-depth strategy (decreased gas production), the overall safety of the situation relative to storage of remediated nitrate salt-bearing waste will be improved because the potential for a self-sustaining thermal runaway leading to a release of radioactive material is eliminated. More succinctly, by adding reliable pressure relief, the accident can be prevented. These concepts were reviewed by the "Pennebaker Chaired" Peer Review Team, which made the following recommendation:

"Based on the results showing the effect of venting (or relieving pressure) on a self-sustaining thermal runaway [xi], additional venting or pressure relief should be considered during "safeing" of RNS drums prior to processing." xii

Reliable pressure relief can be provided by adding a rupture disk to each container. The Laboratory has qualified vendors that can provide Management Level 1 rupture disks that meet all Quality Assurance requirements. As an additional defense in depth feature, supplemental filtration can be provided in the form of a filter. A supplemental filtered vent path will serve defense in depth in that it will minimize pressure in the containers and minimize the potential for a contamination release in the event of an inadvertent or low pressure burst of the rupture disk.

Addition of a Pressure Relief Device (PRD), Supplemental Filter (SF) and Temperature Control The addition of a pressure relief device and a supplemental filter will require access to the RNS drums in storage. Until the PRD or SF is implemented, we will reduce the probability of runaway through the use of temperature control, which will also allow the SWB lids to be removed and the PRD and SF installed. We note that thermally sensitive materials exhibit the following behavior: the lower the exotherm onset temperature, the more reactive are the species and the greater their subsequent depletion at/or near room temperature. Thus, it is intriguing to ask, in the absence of mixing of the heterogenous nitrate salt/Swheat mixture, do low temperature reactants still exist within the drum that could initiate runaway chemical reaction? Or have they been consumed through low-temperature reactivity in a manner such that the heat generated is below that which could be dissipated by the drum, preventing thermal runaway? Could a drum, in environmentally controlled storage, thermally runaway after 600 days? From a practical perspective, we have evidence that the passage of time depletes the low-temperature reactivity, creating a material that requires significantly higher temperatures to induce thermal runaway.xi In the drum tests, the drum held at 25 °C that was vented, exhibited no anomalous behavior through the nominally 84 day observation period. However, this drum was inadvertently heated to 60 °C on Day 95 for over a week, and while it exhibited some self-heating, it was not accompanied by a large increase in gas pressure, and the self-heating did not lead to thermal runaway. This implies that the chemical potential of the drum was reduced from that created on Day 1, presumably through depletion of the low-temperature gas generating reactions that occurred over time.

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In addition to this practical, experimental work, an analysis of the likelihood of thermal runaway, given the length of time that has passed since the drum contents were created, was conducted.\*\*

A brief summary from the report is as follows:

"In order for one of the LANL nitrate salt drums to undergo thermal runaway, the rate of heat production by the chemistry occurring in the drum must be greater than is dissipated to the environment. In order to get long-time thermal runaways, the chemical heat production must be very closely balanced to heat dissipation. If the chemistry produces heat much faster than it is dissipated, then thermal runaway occurs in a relatively short time frame. It is hypothesized that the combination of thermal parameters which would lead to thermal runaway after the long storage time is so unlikely that the probability of thermal runaway now occurring is extremely unlikely.

This hypothesis is presented with several caveats: that the material in the drums is well-mixed and homogeneous, that the chemistry occurring in the drums can be described as one chemical reaction—that is, the chemistry obeys first order Arrhenius kinetics, and the drums will not be subjected to any additional thermal insults.

This hypothesis is tested by using a computational model of the LANL nitrate salt drums to explore the thermal runaway times over a set of kinetic parameters. It will be shown that the slice of parameter space that could possibly lead to thermal runaway is so small that, given the caveats above, the probability of another thermal runaway occurring is beyond extremely unlikely, assuming environmental conditions remain constant."

Essentially, the theoretical analysis supports the practical experiment, in that over time, as the reactants are depleted, the chemical potential is significantly reduced and the likelihood of thermal runaway no longer exists, barring upset environmental conditions. The analysis did show that thermal runaway could be triggered by changing the environmental conditions, such as heating to temperatures that are beyond what the material had experienced in storage. However, the analysis and experiment implies that the material is safe, as long as the NFT filter remains capable of venting the product gases and as long as the environmental conditions (temperature) do not exceed the historical values.

From the practical viewpoint of implementing temperature and pressure control, the following statements apply:

- While it is expected that significant manipulation would be required to induce mixing, the
  interaction with the container should be minimized, to prevent inadvertent mixing. This control
  can be relaxed one the PRD and SF are added, since they will eliminate the possibility of thermal
  runaway.
- From the analysis provided by Heatwole that the drums are safe barring changing environmental conditions, the average temperature of the operation and of the waste leading up to the operation, should be held at temperatures below the maximum average temperature that the waste has experienced. This would be at temperatures ≤ 75 °F. Due to the significant thermal inertia and low conductivity that the waste exhibits, xiv we do not expect that minor deviations excursions above 75 °F are significant, we would allow temporary excursions > 75 °F and ≤ 85 °F for periods less than 24 hours.
- A simple method to prevent the accident is through the addition of burst disc as the PRD that has flow capacity in excess of the flow rates as measured in the full-scale drum tests (after the disc fails). The accompanying engineering calculations derive flow rates measured in the full-scale tests as well as flow rates that are expected through the burst disc after it breaks. In addition to the flow rate design requirement, the disc is required to break at a pressure that is low enough to quench the runaway reaction. Looking at the data from the full-scale drum tests, a rupture disk set-point of 2 psig will be effective at quenching a runaway reaction. The rupture disk must also

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burst at a pressure less than the pressure that the NFT filter failed in the full-scale tests, which was 14 psi (see text above). A filter with a very low pressure threshold is desirable, but must be balanced with practical design considerations (large discs are required for low pressure failures and are susceptible to pressure transients). As a result, a practical solution is to require failure at 2 psig, which is at a pressure that is well below the failure of the NFT filter observed in the full-scale tests, but with pressure sensitivity and size that is operationally practical.

The choice of the SF flow parameters are also derived from the full scale drum test and exceed
them by a factor of ten or more (see accompanying calculation), which is expected to prevent the
accident. As a result, the addition of a high-flow filter is considered defense-in-depth to prevent
contamination of the Permacon.

CY:

Randy Erickson, ADEM Kiki Torres, ADEM Cheryl Cabbil, ADNHHO Steve Young, ADNHHO Dave Frederici, WD-WPE Paul Newberry, WD-SRS Genevieve Fernandez, WD-SRS Mark Kobi, OS-BSI Sharon Walker, OS-BSI Jim Aris, OS-BSI Julie Minton-Hughes, EWMO Les Sonnenberg, EWMO Stephanie Griego, EWMO David Solms, EWMO ADEM File epccat@lanl.gov

<sup>&</sup>lt;sup>1</sup>Ignitability is defined in 40 CFR Part 261 Subpart C, and for the purposes of this discussion is material that "is not a liquid and is capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture or spontaneous chemical changes and, when ignited, burns so vigorously and persistently that it creates a hazard," or can be characterized as an oxidizer.

W. Veazey, A. R. Schake, P. D. Shalek, D. A. Romero, and C. A. Smith, Waste-Form Development for Conversion to Portland Cement at Los Alamos National Laboratory (LANL) Technical Area 55 (TA-55), LA-13125 (1996).

iii G. Veazey, A. Castaneda, Characterization of TA-55 Evaporator Bottoms Waste Stream, Memo NMT-2:FY96-13, October 26, 1996.

iv Stream Analyzer® represents many years of work by OLI Systems, to create a tool for predicting the behavior of multi-component aqueous systems. The company worked with national laboratories to create a database that addressed the behavior of Hanford wastes.

Y. K. Weisbrod, K. Veirs, D. J. Funk, and D. L. Clark, "Salt Composition Derived from Veazey Composition by Thermodynamic Modeling and Predicted Composition of Drum Contents," LA-UR-xxxx.

vi Differential Scanning Calorimetry (DSC). DSC measures the thermal response of a material by monitoring the heat flow into or out of that material as it is heated at a constant ramp rate. A 1 mg sample of the material is held in a sealed aluminum pan. The pan is placed in an instrumented furnace with an empty reference pan and the furnace

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is ramped at 10 °C/min while heat flow to the sample and reference pans is monitored. Endothermic events require more heat to flow to the sample to keep its temperature increasing at the desired ramp rate. Exothermic events cause the furnace power to be reduced for the same reason. With this method, melts, phase transitions, decomposition, and other features can be quantitatively measured.

Automatic Pressure Tracking Adiabatic Calorimetry (APTAC). APTAC is a measurement that determines the temperature at which a material begins to self-heat and monitors the thermal and pressure behavior of that material during the self-heating. In this test, several grams of material are loaded into a titanium sample bomb that is mounted inside a furnace. The bomb is instrumented with a pressure line and thermocouple that is inserted into the sample. In a typical experiment, the sample is heated in 2 °C steps and the temperature is monitored at each step for some tens of minutes. If there is no indication of self-heating, the next step is taken. If the sample does begin to self-heat, the instrument switches to its tracking mode and ramps the furnace at the same rate that the sample is self-heating. This produces adiabatic conditions – the sample cannot lose heat to the surroundings. The heating stops when the heating rate exceeds the limit of the instrument, the pressure exceeds limits, or the sample temperature exceeds a predetermined threshold. The onset temperature of the self-heating is an important metric for ranking materials relative to one another in terms of thermal stability. The adiabatic nature of the measurement makes this more relevant to larger masses whose thermal conductivity may inhibit heat loss from a hot spot. The onset and rate of heating can also be used to determine kinetic parameters that allow predictions to be made for the material in other scenarios, enabling the development of process parameters for reprocessing of the remediated nitrate salt waste stream.

viii G. Brown, "Remediated Nitrate Salt (RNS) Surrogate Formulation and Testing Standard Procedure," PLAN-TA-9-2443 (U), Rev. B, and the associated analytical report, "M7 Analytical Lab Report 52219", in preparation.

- ix D. L. Clark and D. J. Funk, "Chemical Reactivity and Recommended Remediation Strategy for Los Alamos Remediated Nitrate Salt (RNS) Wastes," LA-UR-15-22393, Los Alamos National Laboratory: Los Alamos, NM, February 17, 2015.
- <sup>x</sup> Waste Isolation Pilot Plant Technical Assessment Team Report, March 17, 2015, SRNL-RP-20147-01198, Rev. 0
  <sup>xi</sup> G. R. Parker, M. D. Holmes, E. M. Heatwole, P. Leonard, and C. P. Leibman, "Drum-scale Testing of the Thermolytic Response of a Remediated Nitrate Salt (RNS) Surrogate Waste Mixture," LA-CP-16-20038 (2016).
  <sup>xii</sup> Summary report of the technical Peer Review Team evaluation of LANL's RNS treatment plans, held at LANL on January 6-7, 2016.
- \*\*\* Heatwole, E.M., "Evaluation of the Likelihood for Thermal Runaway for Nitrate Salt Containers in Storage at LANL" LANL Internal Report, LA-UR-15-29244 (draft, 2015).
- xIV G. R. Parker, E. M. Heatwole, and M. D. Holmes, "Data Report for the Drum-scale Thermal Transport Characterization Study," LA-CP-16-20004 (2016).

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# APPENDIX G Page 1 of 9 Estimated Gas Generation Rate of Surrogate RNS Waste

Calculation Title: Estimated Gas General	
1.0 INITIATION	
1.1 Calculation Status: Prelir	minary Final 🖾
1.2 DCF No.: DCF-84-0375-01189	
1.3 Project ID No: N/A	APPEAR OF THE PERSON OF THE PE
1.4 Superseded Calculation No.: N/A	
1.5 Facility Name(s): Area G	1.8 Organization: WD-WPE
1.7 Structure/ System ID: WASTE	1.8 Structure/ System Name: Waste Management
1.9 Component ID: RPD	1.10 Component Name: Rupture Disc
If "N/A" is checked then explain: 1.13 Associated with Technical Baseline:	
2.0 SECURITY CLASSIFICATION REVI	EW .
2.1 Security Classification:	
A SECTION SERVED ASSESSMENT OF THE SECTION OF THE S	tion, Signature, Date) 208 ES-EWMO, Marn Wast 246-03-2
	(If applicable), Organization, Signature, Date)
AQUADEREADENT REVIEW	
4.1 Independent Review: Requ	red ☑ Not Required □
4.2 Independent Reviewer: (Name, Z Nu Arl Ben Swartz, 235211, ES-EPD, O	mber (If applicable), Organization, Signature, Date)
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E.O FACILITY DESIGN AUTHORITY RE 5.1 Facility Design Authority Representati	

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		I-0375-01188 Rev: 0 Pated Gas Generation Rate of Surrogate RNS Waste	age 2 of 9
6.0 APPRO	VAL SIGNA	TURES	
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7.0 REGIST	ERED PRO	FESSIONAL ENGINEER SEAL:	
		PESSIONAL ENGINEER SEAL:	
8.0 REVISI	ON LOG		
8.0 REVISI 8.1 Rev.		8.3 Description of Change(s)	
8.0 REVISI	ON LOG		
8.0 REVISI 8.1 Rev.	ON LOG	8.3 Description of Change(s)	
8.0 REVISI 8.1 Rev.	ON LOG	8.3 Description of Change(s)	
8.0 REVISI 8.1 Rev.	ON LOG	8.3 Description of Change(s)	
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8.0 REVISI 8.1 Rev.	ON LOG	8.3 Description of Change(s)	

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#### Conduct of Engineering Calculation

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Calculation Title: Estimated Gas Generation Rate of Surrogate RNS Waste

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#### **Estimated Gas Generation Rate of Surrogate RNS Waste**



#### **Conduct of Engineering** Calculation

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Calculation Title: Estimated Gas Generation Rate of Surrogate RNS Waste

#### Purpose

The purpose of this calculation is to determine the gas generation rate of remediated nitrate salt (RNS)-bearing waste using the data from Drum D from full scale drum test described in The Thermodynamic Response of a Surrogate Remediated Nitrate Salts(RNS) Waste Mixture at the Drum Scale (LA-UR-15-29229). The purpose of this calculation is to determine the volume of gas associated with the products of reaction that occurred when a drum of RNS surrogate material was maintained at 60°C. This flow rate of gas formation can then be used to aid in sizing a filter and pressure relief system to place on the RNS drums to accommodate the expected gas generation from RNS waste during storage prior to stabilization.

#### 2.0 Methodology

The approach used to calculate the gas flow rate uses the ideal gas law to:

- a) Determine the number of moles of gas in the drum at time (t) based upon the pressure and temperature data collected during the test;
- Determine the number of moles of gas generated over a set time period (1 minute) by difference;
- determine the expected volumetric flow of gas based upon the expected temperature of the gas and the associated location where the drum will set

The ideal gas law relates volume, pressure, temperature and number of mole of gas:

#### Equation 1 PV = nRT where:

P = pressure in Atmosphere (atm)

V = volume in liters (L)

n = Moles of gas

R = Gas Constant (0.082057 L atm K-1 mol-1)

T = Temperature in degrees Kelvin (K)

The report from the full scale drum test (Report LA-UR-15-29229) provides the following information:

- the volume remaining in the drum (V) prior to the start of the test,
- pressure (P) and,
- temperature (T) readings every 20 seconds.

This drum test was selected because the drum was sealed with a gasket and had no filter vent installed. It is assumed that the drum does not leak until pressures in excessive of 30 psig. There are indications from the pressure data that the drum may have leaked or at least expanded due to pressure build up. For purposes of this calculation the assumption is the drum did not leak and expanded but the expansion was not great enough to adjust the overall drum volume for the purposes of this estimation. For the period of time from the beginning of the test until the pressure reaches 30 psig the number of moles of gas in the drum is calculated using the relationship shown in equation 1:

nt = Pt Vi /R Tt where:

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#### **Estimated Gas Generation Rate of Surrogate RNS Waste**



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Calculation Title: Estimated Gas Generation Rate of Surrogate RNS Waste

Pt = pressure in Atmosphere (atm) at time t = (Pgt (psi) + PLA(psi)) / 14.7 (psi/atm) Pgt= Pressure gauge (psi) at time t

PLA= Atmospheric pressure in Los Alamos = 11.2 psi

Vi = volume in liters (L) of available void space at the start of the test (94.65 L)

nt = Moles of gas at time t

R = Gas Constant (0.082057 L atm K-1 mol-1) T<sub>1</sub> = Temperature in degrees Kelvin (K) at time t

The number of moles generated from time t1 to time t2 (An) is calculated by subtracting n2 from nt. The volume that the number of moles of newly generated gas will occupy is calculated using the ideal gas law. The molar volume of an ideal gas at standard temperature (273.15 K) and pressure (1 atm) is assumed to be 22.4 liters.

Volume of gas generated from t1 to t2 is adjusted to approximate a vented drum at atmospheric pressure conditions at Area G is Vat where:

 $V\Delta_t = \Delta n \times (22.4 \text{ L/mole}) \times (T_t/T_{STP}) \times (P_{STP}/P_{LA})$ 

VΔt = Volume of gas generated from t1 to t2 adjusted to approximate a vented drum @ atmospheric pressure conditions at Area G

Δn = number of moles of gas generated between time t<sub>1</sub> to time t<sub>2</sub>

Tt = gas temperature at time t, (K)

TSTP = standard temperature, (273.15 K)

PSTP = standard pressure, (1 atm)

PLA = atmospheric pressure at Area G, (0.7629 atm)

The flow rate (F) that must be accommodated to prevent the drum from pressurizing is:

 $F = V\Delta / (t_2 - t_1)$ 

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#### **Estimated Gas Generation Rate of Surrogate RNS Waste**



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Calculation Title: Estimated Gas Generation Rate of Surrogate RNS Waste

#### **Acceptance Criteria**

An acceptance criteria does not exist for this calculation. This calculation examines test data and determines the number of moles of gas in the drum at any time t and calculates the volume of space that gas will occupy at selected conditions.

#### Open Items

None.

#### 5.0 **Assumptions**

#### Drum D had a seal that prevented leakage of gas up to 18 psig

Drum D is assumed to be a closed system and capable of holding the gas generated during the test. There are indications from the data that the drum may have been leaking or at least went through small expansions as seen in the experimental video at pressures above 18 psig (time =71.37 hrs). The following excursions from the typical rise in pressure and associated number of moles indicates the drum likely expanded or may have leaked. The following excursions were noted and are highlighted in expense on the data set. noted and are highlighted in orange on the data set.

Time (hrs)	Gas Temp. (°C)	Drum Pressure (psig)	Drum Pressure Change (psig)	Rate of Pressure Increase Prior to Excursion (psi/min)	Rate of Pressure Increase After Excursion (psi/min)
71.38	42.7	18.47	-0.006	0.14	0.09
71.70	43.0	20.13	0.003	0.12	0.09
71.76	43.1	20.27	-0.137	0.10	0.10
71.96	43.5	21.37	-0.112	0.10	0.13
72.18	45.6	23.21	-0.123	0.19	0.26
72.31	49.0	24.79	-0.241	0.22	0.26
72.52	57.8	28.00	-0.136	0.28	0.32
72.66	61.9	30.99	-0.097	0.42	0.42
72.69	65.5	31.44	0.00	0.36	-0.05

Table 1: Pressure Excursions During Drum Test D

For the first 48 hours, the rise in pressure in the drum is primarily caused by the heating of the drum from the external heaters. Once the temperature of the material reaches 31°C, at approximately time 59 hours, the moles of gas increase at a more rapid pace. At 71.38 hours into the test and at a pressure of 18.47 psi, the pressure appears to relieve since the pressure rise stops for about 30 seconds and then again begins to rise. Small pressure drops occur

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#### **Estimated Gas Generation Rate of Surrogate RNS Waste**



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Calculation Title: Estimated Gas Generation Rate of Surrogate RNS Waste

periodically, as shown in Table 1, until the drum losses containment at 72.69 hours into the test and at a pressure of 31.44 psig.

#### Volume available for gas in Drum D

The available volume in Drum D at any time t is estimated to be 25 gallons or 94.65 liters. This was estimated from the pictures shown in the report and in discussions with the authors of the report. This assumes that no gas is dissolved in the solids or held in the matrix. If the available volume for the gas to occupy is expected to be different than 25 gallons then the gas flowrate F at any time t should be adjusted using a ratio of the actual volume (gallons) to 25.

#### F = VA/25

It is assumed that the volume increases of the drum during the test were not significant - less than 10%. Because the flow rate is a direct ratio to the volume of the drum, the maximum flow rate can be increased by 10% to ensure the estimated gas flow rate is bounded by the potential drum volume increase

#### Limitations 6.0

When calculation use is consistent with the objective, there is no limitation associated with this calculation.

#### 7.0 Calculation Inputs

Calculation inputs are from the Drum D Test identified in Report LA-UR-15-29229. Specific data used includes:

- drum pressure (psig),
- drum head space gas temperature thermocouple 11, TC11 (°C),
- estimate of the internal volume found in Drum D prior to start of the test

Other inputs include the standard temperature and pressure values and the atmospheric pressure at 7300 ft (Los Alamos Elevation). These values are:

- standard temperature = 273.15 (K)
- standard pressure = 1 atm
- atmospheric pressure at 7300 ft = 0.7628 atm
- ideal gas constant = 0.08207 L atm K-1 mol-1

#### 8.0 Computer Hardware and Software

Excel 2013, Microsoft Corporation

#### 9.0 Summary and Conclusions

The calculated value of the flow rate (L/min) at any time t is shown in Column K of the Excel spreadsheet. Column L provides and averaged value of the flow (L/min) taking the last four

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#### **Estimated Gas Generation Rate of Surrogate RNS Waste**



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Calculation Title: Estimated Gas Generation Rate of Surrogate RNS Waste

readings prior to time t and averaging them. This allows for adjusting for instrument error. Table 2 presents selected test data at various time during Drum Test D.

Table 2: Selected Data and Associated calculated Gas Flow Rate from Drum D Test

Time (hrs)	Waste Temp (°C)	Gas Temp (°C)	Drum Pressure (psig)	Gas Moles (#)	Gas Generation Rate (L/min)**
0	10.8	12.8	0.09	3.10	0
12	12.4	9.9	0.19	3.16	0
24	21.1	22.6	0.69	3.15	0
36	22.1	19.6	1.00	3.27	0
48	30.0	29.0	2.04	3.44	0.0
60	31.4	27.4	3.69	3.89	0.06
66	39.9	38.4	6.46	4.45	0.10
67	40.9	39.2	7.40	4.67	0.11
68	42.2	. 40.1	8.69	4.98	0.21
69	43.2	40.7	10.64	5.46	0.38
70	44.1	41.2	13.27	6.11	0.42
71	45.4	42.4	16.79	6.96	0.57
72*	47.2	43.6	21.73	8.16	1.15
72.66*	92.9	63.5	30.99	9.83	2.67

<sup>\*</sup> Indications of pressure loss during this time period

The highest 1 min average flow rate found from the available data is 2.77 liters/minute of gas or 3.77 It/min during the last 20 seconds when adjusted for an atmospheric drum. This flow rate occurs just prior to the drum breaching and losing pressure, indicating a large leak had occurred. It is possible that the drum was leaking prior to 72.66 hours into the test.

#### 10.0 References

LA-UR-15-29229

Excel was used to carry out the calculations associated with the ideal gas law. The following calculations were performed on the data received from the Drum D Test:

Convert the pressure data (column C) from psig to atm (column D)

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<sup>\*\* 4</sup> minute average flow rate for a well vented drum at atmospheric pressure

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### **Estimated Gas Generation Rate of Surrogate RNS Waste**



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Calculation Title: Estimated Gas Generation Rate of Surrogate RNS Waste

- o C/14.7 = Dx
- Convert the drum head space gas temperature data from thermocouple11(column F) from degrees Celsius to Kelvin (column G)
- Calculate the number of moles of gas (column H) in the drum from available pressure data (column D) and temperature data (column G)
  - o  $(D_x^*94.65)/(0.08207^*G_x) = H_x$
- Calculate the volume of moles of gas generated over the last minute (column K) in liters using the total moles of gas in the drum at time t (column H) and expanding the volume for temperature and pressure differences
  - $o =+((H_x-H_{x-3})^*22.4)^*(G_x/273.15)^*($P$4/$P$5)$
  - o Where \$P\$4 is the standard pressure = 1 atm
  - o Where \$P\$5 is the atmospheric pressure at 7300 ft = 0.7628

See attached Excel spreadsheet for the results.

Appendix A - Excel spreadsheet with calculation results

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NATIONAL LABORATORY			t of Engineering n Cover Sheet
Calculation No.: CAL-99-MULT-01257 Calculation Title: Drum POC Lid Vent Flow	ate Evaluation	Rev:0	Page 1 of 15
1.0 INITIATION			
1.1 Calculation Status: Prelimina	ary 🗌	Final 🛛	
1.2 DCF No.: DCF-54-TBD			
1.3 Project ID No: Drum POC Lid Vent Flow	vrate Evaluation		
1.4 Superseded Calculation No.: NA			THE REAL
1.5 Facility Name(s): 54-375	1.6 Organization:	ADEM	of any three successions
1.7 Structure/ System ID: Drums	1.8 Structure/ Sys	tem Name: NA	
1.9 Component ID: NA	1.10 Component N	lame: Drum Rupti	re Disc
1.11 Structure, System, or Component Nucl			3 Calculation
1.12 Structure, System, or Component Man ML-1 ML-2 ML-3	A CONTRACTOR OF CHICAGO	SB Calculation	□ N/A □
If "N/A" is checked then explain:			
	Yes 🗌	No ⊠	
1.13 Associated with Technical Baseline:		No ⊠	
1.13 Associated with Technical Baseline: 2.0 SECURITY CLASSIFICATION REVIEW		No ⊠	
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Charles Commission of	No.: CAL-54-0 Title: Flow Cap	0375-01192 acity of Drum Rupture D	isc Assembly	Rev:0	Page 2 of 8
5.0 FACILI	TY DESIGN AU	THORITY REPRESENTA	ATIVE REVIEW		
5.1 Facility	Design Authority	Representative Review	Required 🛛		Not Required
Julia Elizab	eth Minton-Hugl	y Representative: (Name nes, 112196, 112196	z Number, Org	anization, Sig	nature, Date) 7/20/2016
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6.2 Subcon	tractor Approve	'6/27   16 r: (Name, Z Number (if ap			ature, Date)
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### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



Conduct of Engineering Calculation

Calculation No.: CAL-99-MULT-01257

Calculation Title: Drum POC Lid Vent Flowrate Evaluation

Rev:0

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#### 1.0 Purpose

Determine the volumetric flowrate through the POC lid vent holes.

#### 2.0 Methodology

The calculation model will be as a series of resistances utilizing the K "resistance coefficient" sum of the resistances in series (equation 6-24).

Ktotal = K1 + K2 + ... Kn

#### 3.0 **Acceptance Criteria**

- Volumetric flow at 1" of water column = 0.2 L/min (0.0070 scfm)(3/4 NFT filter flow)
- Volumetric flow at 1° of water column = 37.7 L/min (1.331 scfm) (Design Basis of PRDwSF)
  Volumetric flow at 4 psig = 377 L/min (13.313 scfm) (Pressure relief flow required at elevated conditions)

#### 4.0 Open Items

None

#### 5.0 Assumptions

- Use air as gas for initial simulation
- Air is at Standard Temperature and Pressure (STP)
- 6 inch pipe is schedule 40 per ASME B36.10m-2006
- Assume friction factor for 1 inch pipe and 1 inch tee (verify at end)
- Gas assumed to be ideal (Z=1)
- Small holes are centered in plate (for beta ratio calculation)
- Use of minor diameter for 3/8 NPSM exit size (0.958 inch)
- All entrances and exits are sharp edges
- Use smallest hole diameter based on tolerances (0.094-.005 = 0.089 inch)
- Absolute roughness is equal to drawn tubing 0.00152 mm (e)
- Crane 410 equations 2-17 and 2-18 were used because 2-25 and 2-27 are even more restrictive (less flow).

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### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



Conduct of Engineering Calculation

Calculation No.: CAL-99-MULT-01257

Calculation Title: Drum POC Lid Vent Flowrate Evaluation

Rev:0

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#### 1.0 Purpose

Determine the volumetric flowrate through the POC lid vent holes.

#### 2.0 Methodology

The calculation model will be as a series of resistances utilizing the K "resistance coefficient" sum of the resistances in series (equation 6-24).

Ktotal = K1 + K2 + ... Kn

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- Volumetric flow at 1" of water column = 0.2 L/min (0.0070 scfm)(3/4 NFT filter flow)
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  Volumetric flow at 4 psig = 377 L/min (13.313 scfm) (Pressure relief flow required at elevated conditions)

#### 4.0 Open Items

None

#### 5.0 Assumptions

- Use air as gas for initial simulation
  Air is at Standard Temperature and Pressure (STP)
  6 inch pipe is schedule 40 per ASME B36.10m-2006
  Assume friction factor for 1 inch pipe and 1 inch tee (verify at end)
  Gas assumed to be ideal (Z=1)
  Small holes are centered in plate (for beta ratio calculation)
  Use of minor diameter for 3/8 NPSM exit size (0.958 inch)
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- All entrances and exits are sharp edges
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Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



Conduct of Engineering Calculation

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Calculation Title: Drum POC Lid Vent Flowrate Evaluation

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#### 6.0 Limitations

Math model accuracy is limited by assumptions that center the holes in the flow stream for evaluation of beta ratios.

The flow Reynold's Number (Re) for the evaluation of 1 inch water column differential pressure puts the flow in the transition region between laminar and true turbulent flow. Consequently, the evaluation is performed for both cases. The actual flow regime is unknown.

#### 7.0 **Calculation Inputs**

Two initial cases:

Pressure differential is 1 inch water column

Pressure differential is 4 psig

#### 8.0 **Computer Hardware and Software**

None

#### **Summary and Conclusions**

Evaluation	Differential (ft^3/min) (ft/ (psi)		q (total) (ft^3/min)	Pass/Fail .
1A, Laminar	0.0361	0.1381	0.5524	Pass; ¾ NFT filter flow 0.2 L/min (0.0070 scfm) Fail, PRDwSF 37.7 L/min (1.331 scfm)
1B, Turbulent	0.0361	0.1352	0.5409	Pass; % NFT filter flow 0.2 L/min (0.0070 scfm) Fail, PRDwSF 37.7 L/min (1.331 scfm)
2	4	1.4535	5.8143	Fail elevated conditions test, 377 L/min (13.313 scfm)

- Volumetric flow at 1" of water column = 0.2 L/min (0.0070 scfm)(3/4 NFT filter flow)
- Volumetric flow at 1" of water column = 37.7 L/min (1.331 scfm) (Design Basis of PRDwSF)
- Volumetric flow at 4 psig = 377 L/min (13.313 scfm) (Pressure relief flow required at elevated conditions)

#### 10.0 References

- Crane Technical Paper No. 410 Flow of Fluids Through Valves, Fittings, and Pipes
- Perry's Chemical Engineers' Handbook 8th Edition, James O. Maloney, 2008 McGraw-Hill Companies Inc., ISBN 0-07-154208-6

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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



#### Conduct of Engineering Calculation

Calculation No.: CAL-99-MULT-01257

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Calculation Title: Drum POC Lid Vent Flowrate Evaluation

#### Calculation

Sum of K Calculation:

The calculation model will be as a series of resistances utilizing the K "resistance coefficient". sum of the resistances in series (equation 6-24) Ktotal = K1 + K2 + ... Kn

Case 1A: 1 inch water column differential pressure (Laminar)

Summary List of K's:

K#	Description	Value	Citation
K1	Inlet to Hole	0.5	page A-30 sharp edged entrance
K2	0.089 inch Hole in flange pipe	0.08425	page 6-4, K=f(L/D) Equation 6-21 (f is assumed to be 0.025 for 1 inch water column differential pressure laminar flow, and 0.045 inch turbulent flow, f is assumed to be 0.026 for 4 psig differential pressure)
КЗ	Expansion from hole in flange to machined area	0.9827	page A-27 sudden expansion angle = 180
Ktotal	Sum of all K's	1.56695	

### Calculation for Expansion and Contraction: Assume friction factor for drilled hole

Item	D Inside Diameter (inch)	Length (inch)	L/D	f Friction Factor (initial guess)	K = f(L/D)	K#
6 inch pipe	6.065	na		Taylor to tolo		
Drilled hole	0.089	0.3	3.37	0.025	0.08425	K2
¾ NPSM	0.958	na				

#### **Expansion and Contractions:**

Item	D Inside Diameter (inch)	Crane Formula	Large Diameter	Small Diameter	Beta	к	К#
6 inch pipe	6.065	2-18	6.065		0.01467	0.5	K1
Drilled hole	0.089			0.089			
¾ NPSM	0.958	2-17	0.958		0.093	0.9827	КЗ

Beta = small diameter/large diameter Beta (K1) = 0.089/6.065 = 0.01467 Beta (K2) = 0.089/.958 = 0.93

K = 0.5 (1-beta<sup>2</sup>) K1 = 0.5 (1-0.01467<sup>2</sup>) K1 = 0.49989 = 0.5

(Equation 2-18)

K = (1-beta^2)^2

(Equation 2-17)

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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



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Calculation No.: CAL-99-MULT-01257

Calculation Title: Drum POC Lid Vent Flowrate Evaluation

(Equation 6-19)

K3 = (1-0.093^2)^2 K3 = 0.9827

Velocity Calculation:

hl = f(L/D)v^2/2g K = f(L/D) (Equation 6-21) hl = Kv^2/2g (Equation 6-20)

 $\begin{array}{ll} DeltaP = (rho/144)(Kv^2/2g) & (Equation 6-22) \\ v^2 = & (144/rho)^*DeltaP^*(2g/K) = 288^*DeltaP^*/(rho Ktotal) \\ v = & [288^*DeltaP^*/(rho K)]^4/2 \end{array}$ 

Variables: DeltaP = 0.0361 lbf/in^2 K = Ktotal = 1.56695 Rho = 0.0752 lb/ft^3 g = 32.174 ft/s

v (ft/s) = [288\*32.174\*0.0361 / (0.0752\*1.56695)]^1/2 v = (334.5 / 0.11783)^1/2  $v = 53.28 \, \text{ft/s}$ 

Reynolds Number Calculation:

Re = D\*v\*rho/mewe D = 0.089 in /12 = 7.416667x10-3 ft v = 53.28 ft/sRho = 0.0752 lbm/ft^3

Mewe = 0.017 cP 1cP = 6.7197x10-4 lbm/(ft-s)

Mewe = 0.017 cP x 6.7197x10-4 (lbm/ft s /1cP) = 1.14x10-5 lbm/(ft s)

Re = 7.416667x10-3 \* 53.28 \* 0.0752 / 1.14x10-5 (all units cancel) Re = 2606 (2.6x10+3)

Absolute roughness = 0.00152 mm e = 0.00152 mm x 1/25.4 e = 0.000 059 842 519 685 inch (5.9842x10-5)

e/D = 5.9842x10-5 / 0.089 e/D = 6.738x10-4

NOTE: this Reynolds' Number is in the transition range and flow can be either laminar or turbulent

Laminar range: On Table A-25 the equation is: f = 64/Ref = 64/2606 f = 0.0245587

f(initial guess) = 0.025

Conclusion, interation is complete. Assumed friction factors acceptable

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### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



#### Conduct of Engineering Calculation

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#### Volumetric Rate Calculation:

Item	D Inside Diameter (inch)	A Area (ft^2)	Velocity (v) ft/s	Velocity (v) ft/min	q (each) (ft^3/min)	q (total) (ft^3/min)
Drilled hole	0.089	4.32x10-5	53.28	3196.8	0.1381	0.5524

v = q/A (mean velocity; Equation 1-10)

A (ft) = pi\*(D/2)\*2/144 A = pi (0.089)\*2/(4\*144) v = 53.28 ft/s

v = 53.28 ft/s x 60s/min = 3196.8 ft/min

q volumetric flowrate (ft^3/min) = Area (ft^2) \* v (ft/min)

q = 4.32x10-5 x 3196.8 = 0.1381 (ft^3/min)

q (total) = 4 \* 0.1381 = 0.5524 (ft^3/min)

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Calculation Title: Drum POC Lid Vent Flowrate Evaluation

Case 1B: 1 inch water column differential pressure (Turbulent)

Summary List of K's:

K#	Description	Value	Citation
K1	Inlet to Hole	0.5	page A-30 sharp edged entrance
K2	0.089 inch Hole in flange pipe	0.15165	page 6-4, K=f(L/D) Equation 6-21 (f is assumed to be 0.025 for 1 inch water column differential pressure laminar flow, and 0.045 inch turbulent flow; f is assumed to be 0.026 for 4 psig differential pressure)
КЗ	Expansion from hole in flange to machined area	0.9827	page A-27 sudden expansion angle = 180
Ktotal	Sum of all K's	1.63435	

### Calculation for Expansion and Contraction: Assume friction factor for drilled hole

Item	D Inside	L Length (inch)	L/D	f Friction Factor	K = f(L/D)	K#
	Diameter (inch)			(initial guess)		- Televi
6 inch pipe	6.065	na				
Drilled hole	0.089	0.3	3.37	0.046	0.15165	.K2
¾ NPSM	0.958	na				

#### **Expansion and Contractions:**

Item	D Inside Diameter (inch)	Crane Formula	Large Diameter	Small Diameter	Beta	К	K#
6 inch pipe	6.065	2-18	6.065		0.01467	0.5	K1
Drilled hole	0.089			0.089			
3/4 NPSM	0.958	2-17	0.958		0.093	0.9827	K3

Beta = small diameter/large diameter Beta (K1) = 0.089/6.065 = 0.01467 Beta (K2) = 0.089/.958 = 0.93

K = 0.5 (1-beta^2) K1 = 0.5 (1-0.01467^2) K1 = 0.49989 = 0.5

(Equation 2-18)

K = (1-beta^2)^2 K3 = (1-0.093^2)^2 K3 = 0.9827

(Equation 2-17)

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Velocity Calculation: hl = f(L/D)v^2/2g K = f(L/D) (Equation 6-21) hl = Kv^2/2g (Equation 6-20)

(Equation 6-19)

DeltaP =  $(rho/144)(Kv^2/2g)$ (Equation 6-22) v^2 = (144/rho)\*DeltaP\*(2g/K) = 288\*DeltaP\*/(rho Ktotal) v = [288\*DeltaP\*/(rho K)]^1/2

Variables: DeltaP = 0.0361 lbf/in^2 K = Ktotal = 1.63435 Rho = 0.0752 lb/ft^3 g = 32.174 ft/s

v (ft/s) = [288\*32.174\*0.0361 / (0.0752\*1.63435)]^1/2 v = (334.5 / 0.1229)^1/2 v = 52.17 ft/s

#### Reynolds Number Calculation:

Re = D\*v\*rho/mewe D = 0.089 in /12 = 7.416667x10-3 ft v = 52.17 ft/sRho = 0.0752 lbm/ft^3

Mewe = 0.017 cP 1cP = 6.7197x10-4 lbm/(ft-s) Mewe = 0.017 cP x 6.7197x10-4 (lbm/ft s /1cP) = 1.14x10-5 lbm/(ft s)

Re = 7.416667x10-3 \* 52.17 \* 0.0752 / 1.14x10-5 (all units cancel) Re = 2552 (2.6x10+3)

Absolute roughness = 0.00152 mm e = 0.00152 mm x 1/25.4 e = 0.000 059 842 519 685 inch (5.9842x10-5)

e/D = 5.9842x10-5 / 0.089 e/D = 6.738x10-4

NOTE: this Reynolds' Number is in the transition range and flow can be either laminar or turbulent

Turbulent range: On Table A-25 read the intersection of the lines from e/D and Re e/D = 6.738x10-4 Re = 2552 (2.6x10+3)

From graph f = 0.0455

f(initial guess) = 0.045

Conclusion, iteration is complete Assumed friction factors acceptable

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### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



**Conduct of Engineering** Calculation

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#### Volumetric Rate Calculation:

Item	D Inside Diameter (inch)	A Area (ft^2)	Velocity (v) ft/s	Velocity (v) ft/min	q (each) (ft^3/min)	q (total) (ft^3/min)
Drilled hole	0.089	4.32x10-5	52.17	3130.2	0.1352	0.5409

v = q/A (mean velocity; Equation 1-10)

A (ft) = pi\*(D/2)^2/144 A = pi (0.089)^2/(4\*144) v = 52.17 ft/s v = 52.17 ft/s x 60s/min = 3130.2 ft/min

q volumetric flowrate (ft^3/min) = Area (ft^2) \* v (ft/min)

q = 4.32x10-5 x 3130.2 = 0.1352 (ft^3/min)

q (total) = 4 \* 0.1352 = 0.5409 (ft^3/min)

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Calculation Title: Drum POC Lid Vent Flowrate Evaluation

Case 2: 4 psig differential pressure

Summary List of K's:

K#	Description	Value	Citation
K1	Inlet to Hole	0.5	page A-30 sharp edged entrance
К2	0.089 inch Hole in flange pipe	0.08425	page 6-4, K=f(U/D) Equation 6-21 (f is assumed to be 0.025 for 1 inch water column differential pressure laminar flow, and 0.045 inch turbulent flow; f is assumed
Charles of	THE PERSON NAMED IN COLUMN TWO IS NOT THE OWNER.	TOWNS OF THE PARTY	to be 0.026 for 4 psig differential pressure)
КЗ	Expansion from hole in flange to machined area	0.9827	page A-27 sudden expansion angle = 180
Ktotal	Sum of all K's	1.56695	

### Calculation for Expansion and Contraction: Assume friction factor for drilled hole

Item	D Inside Diameter (inch)	L Length (inch)	L/D	f Friction Factor (initial guess)	K = f(L/D)	K#
6 inch pipe	6.065	na				1.77
Drilled hole	0.089	0.3	3.37	0.025	0.08425	K2
3/4 NPSM	0.958	na	1			15

#### **Expansion and Contractions:**

Item	D Inside Diameter (inch)	Crane Formula	Large Diameter	Small Diameter	Beta	К	K#
6 inch pipe	6.065	2-18	6.065		0.01467	0.5	K1
Drilled hole	0.089			0.089			
3/4 NPSM	0.958	2-17	0.958		0.093	0.9827	КЗ

Beta = small diameter/large diameter Beta (K1) = 0.089/6.065 = 0.01467 Beta (K2) = 0.089/.958 = 0.93

(Equation 2-18)

K = 0.5 (1-beta^2) K1 = 0.5 (1-0.01467^2) K1 = 0.49989 = 0.5

K = (1-beta^2)^2 K3 = (1-0.093^2)^2 K3 = 0.9827

(Equation 2-17)

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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



#### Conduct of Engineering Calculation

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(Equation 6-19)

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Velocity Calculation: hI = f(L/D)v^2/2g K = f(L/D) (Equation 6-21) hl = Kv^2/2g (Equation 6-20)

DeltaP = (rho/144)(Kv^2/2g) (Equation 6-22) v^2 = (144/rho)\*DeltaP\*(2g/K) = 288\*DeltaP\*/(rho Ktotal) v = [288\*DeltaP\*/(rho K)]\*1/2

<u>Variables:</u>
DeltaP = 4 lbf/in^2
K = Ktotal = 1.56695
Rho = 0.0752 lb/ft^3 g = 32.174 ft/s

v (ft/s) = [288\*32.174 \* 4 / (0.0752\*1.56695)]^1/2 v = (3656 / 0.11783)^1/2  $v = 560.8 \, \text{ft/s}$ 

#### Reynolds Number Calculation:

Re = D\*v\*rho/mewe D = 0.089 in /12 = 7.416667x10-3 ft v = 560.8 ft/sRho = 0.0752 lbm/ft^3

Mewe = 0.017 cP 1cP = 6.7197x10-4 lbm/(ft-s) Mewe = 0.017 cP x 6.7197x10-4 (lbm/ft s /1cP) = 1.14x10-5 lbm/(ft s)

Re = 7.416667x10-3 \* 560.8 \* 0.0752 / 1.14x10-5 (all units cancel) Re = 27436 (2.75x10+4 turbulent)

Absolute roughness = 0.00152 mm e = 0.00152 mm x 1/25.4 e = 0.000 059 842 519 685 inch (5.9842x10-5)

e/D = 5.9842x10-5 / 0.089 e/D = 6.738x10-4

On Table A-25 read the intersection of the lines from e/D and Re e/D = 6.738x10-4 Re = 27436 (2.75x10+4 turbulent)

From graph f = 0.0257

f(initial guess) = 0.025

Conclusion, iteration is complete. Assumed friction factors acceptable

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#### Volumetric Rate Calculation:

Item	D Inside Diameter (inch)	A Area (ft^2)	Velocity (v) ft/s	Velocity (v) ft/min	q (each) (ft^3/min)	q (total) (ft^3/min)
Drilled hole	0.089	4.32x10-5	560.8	33648	1.4535	5.8143

v = q/A (mean velocity; Equation 1-10)

A (ft) = pi\*(D/2)\*2/144 A = pi (0.089)\*2/(4\*144) v = 560.8 ft/s

v = 560.8 ft/s x 60s/min = 33648 ft/min

q volumetric flowrate (ft^3/min) = Area (ft^2) \* v (ft/min)

q = 4.32x10-5 x 33648 = 1.4535 (ft^3/min)

q (total) = 4 \* 1.4535 = 5.8143 (ft^3/min)

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Appendix A – Supporting Information
Crane Flow of Fluids TP-410 pages 1-4, 2-10, 2-11, 6-4, 6-5, A-6, A-9, A-25, B-3
Perry's Chemical Engineering Handbook page 6-10 (Table 6-1 surface roughness)
ASME B1.20.1 (NPSM dimensions)
ASME B36.19M-2004 page 4 (pipe dimensions)
Sketch of POC lid vent

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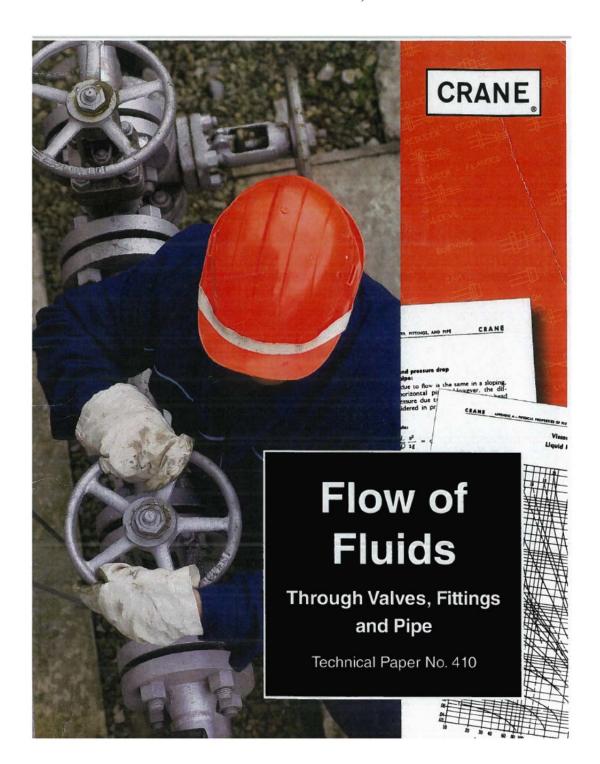
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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257

CRANE

### Nature of Flow in Pipe - Laminar and Turbulent



Figure 1-1: Laminar Flow This is an illustration of colored filaments being carried along undisturbed by a stream of water.



Figure 1-2: Flow in Critical Zone At the critical velocity, the filaments begin to break up, indicating flow is becoming



Figure 1-3: Turbulent Flow This illustration shows the turbulence in the stream completely dispersing the colored filaments a short distance downstream from the point of injection.

A simple experiment (illustrated above) will readily show there are two entirely different types of flow in pipe. The experiment consists of injecting small streams of a colored fluid into a liquid flowing in a glass pipe and observing the behavior of these colored streams at different sections downstream from their points of injection

If the discharge or average velocity is small, the streaks of colored fluid flow in straight lines, as shown in Figure 1-1.

As the flow rate is gradually increased, these streaks will continue to flow in straight lines until a velocity is reached when the streaks will waver and suddenly break into diffused patterns, as shown in Figure 1-2. The velocity at which this occurs is called the "critical velocity." At velocities higher than "critical," the filaments are dispersed at random throughout the main body of the fluid, as shown in Figure 1-3.

The type of flow which exists at velocities lower than "critical" is known as laminar flow and, sometimes, as viscous or streamline flow. Flow of this nature is characterized by the gliding of concentric cylindrical layers past one another in orderly fashion. Velocity of the fluid is at its maximum at the pipe axis and decreases sharply to zero at the wall.

At velocities greater than "critical," the flow is turbulent. In turbulent flow, there is an irregular random motion of fluid particles in directions transverse to the direction of the main flow. The velocity distribution in turbulent flow is more uniform across the pipe diameter than in laminar flow. Even though a turbulent motion exists throughout the greater portion of the pipe diameter, there is always a thin layer of fluid at the pipe wall, known as the "boundary layer" or "laminar sub-layer," which is moving in laminar flow.

Mean velocity of flow: The term "velocity," unless otherwise stated, refers to the mean, or average, velocity at a given cross section, as determined by the continuity equation for steady state flow:

$$v = \frac{q}{A} = \frac{w}{A\rho} = \frac{w\overline{V}}{A}$$
 Equation 1-10

"Reasonable" velocities for use in design work are given on page A-10.

Reynolds number: The work of Osborne Reynolds has shown that the nature of flow in pipe (whether it is laminar or turbulent) depends on the pipe diameter, the density and viscosity of the flowing fluid, and the velocity of flow. The numerical value of a dimensionless combination of these

four variables, known as the Reynolds number, may be considered to be the ratio of the dynamic forces of mass flow to the shear stress due to viscosity. Reynolds number is:

$$Re = \frac{Dv\rho}{\mu_e}$$
 Equation 1-11

(other forms of this equation; page 6-2.)

For engineering purposes, flow in pipes is usually considered to be laminar if the Reynolds number is less than 2000. and turbulent if the Reynolds number is greater than 4000. Between these two values lies the "critical zone" where the flow (being laminar, turbulent, or in the process of change, depending upon many possible varying conditions) is unpredictable. Careful experimentation has shown that the laminar zone may be made to terminate at a Reynolds number as low as 1200 or extended as high as 40,000, but these conditions are not expected to be realized in ordinary

Noncircular Conduit: When a conduit of noncircular cross section is encountered, the equivalent hydraulic diameter (equal to four times the hydraulic radius) should be used as a substitute for diameter in Reynolds number, friction factor, relative roughness and resistance value calculations.

$$R_{H} = \frac{cross\ sectional\ area}{wetted\ perimeter}$$
 Equation 1-12

This applies to any ordinary conduit (partially full circular, oval, square or rectangular conduit) under turbulent flow, but does not apply to laminar flow conditions. For extremely narrow shapes such as annular or elongated openings, where width is small relative to length, hydraulic radius may not provide accurate results.

Equivalent diameter is the diameter of a circular pipe that gives the same area as a noncircular conduit and is substituted for diameter in equations where velocity and flow are calculated. This should not be confused with equivalent hydraulic diameter.

For example, to determine flow rate for a noncircular conduit using Equation 1-13:

$$q = \frac{\pi d^2}{4} \sqrt{\frac{2gh_L D}{fL}}$$
 Equation 1-13

the value d is replaced with the equivalent diameter of the actual flow area and 4R<sub>H</sub> (equivalent hydraulic diameter) is substituted for D.

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CRANE

### Resistance Coefficient K, Equivalent Length L/D, and Flow Coefficient C

compressible flow (explained on page 1-8) apply. Other convenient forms of Equations 2-3 and 2-10 in terms of commonly used units are presented on page 6-4.

Use of flow coefficient for piping and components: The flow coefficient can also be used to characterize the hydraulic performance of any valve, fitting, pipeline, or combination of fixed resistance components in a system. If the flow rate and differential pressure across the components are known, an equivalent C<sub>v</sub> can be calculated, as shown in Figure 2-10 for the flow of water at 60°F.

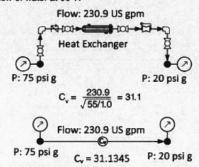


Figure 2-10: Equivalent C, calculated for fixed resistance piping components with only flow rate and differential pressure known

Using the equivalent  $\mathrm{C}_{\mathrm{V}}$  the flow rate at a different pressure drop can be calculated, or the pressure drop can be calculated for a given flow rate, assuming the resistance of all components remains fixed.

Flow coefficients for pipelines, valves and fittings in series and parallel: As with the resistance coefficient, an equivalent total flow coefficient can be calculated to represent the hydraulic performance of multiple piping components in series or parallel. For components in series, the equivalent total flow coefficient can be calculated as follows:

$$\frac{1}{C_{v_{Total}}^{2}} = \frac{1}{C_{v_{1}}^{2}} + \frac{1}{C_{v_{2}}^{2}} + \cdots \frac{1}{C_{v_{n}}^{2}}$$

Equation 2-12

For components in parallel, the equivalent total flow coefficient can be calculated as the sum of the individual flow coefficients of each component:

$$C_{\nu_{Total}} = C_{\nu_1} + C_{\nu_2} + \cdots C_{\nu_n}$$
 Equation 2-13

**Laminar Flow Conditions** 

Flow will change from laminar to turbulent, typically within a range of Reynolds numbers from 2000 to 4000, defined as the critical zone and illustrated on pages A-25 and A-26. The lower critical Reynolds number of 2000 is usually recognized as the upper limit for the application of Poiseuille's law for laminar flow in straight pipes,

$$h_L = 0.0962 \frac{\mu L v}{d^2 \rho}$$
 Equation 2-14

which is identical to Equations 2-1 when the value of the friction factor for laminar flow,  $f=64/R_{\rm e}$ , is factored into it. Laminar flow at Reynolds numbers above 2000 is unstable, and in the critical zone and lower range of the transition zone, turbulent mixing and laminar motion may alternate unpredictably.

Equation 2-3 is valid for computing the head loss due to valves and fittings for all conditions of flow, including laminar flow, using the resistance coefficient. If the assumption is made that the resistance coefficient is constant for all flow conditions, K may be obtained from the K Factor Table which uses the turbulent friction factor for clean commercial steel pipe and the equivalent length ratio L/D.

When Equation 2-3 is used to determine the losses in straight pipe, it is necessary to compute the Reynolds number in order to establish the friction factor to be used to determine the value of the resistance coefficient for the pipe in accordance with Equation 2-4. See Examples 7-7 through 7-9.

Adjusting the resistance coefficient for Reynolds number: Recent studies suggest that for flow regimes other than completely turbulent, the frictional forces within a valve or fitting become more influential compared to the changes in direction, cross-sectional shape, or obstructions in the flow passage. This results in an increase in the resistance coefficient as the friction factor increases with decreasing Reynolds number in the transition and laminar regions, as shown in studies presented by Miller and Idelchik. 18,19

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CRANE

#### Contraction and Enlargement

The resistance to flow due to sudden enlargements may be expressed by,

$$K_1 = \left(1 - \frac{d_1^2}{d_2^2}\right)^2$$

Equation 2-15

and the resistance due to sudden contractions, by

$$K_1 = 0.5 \left( 1 - \frac{d_1^2}{d_2^2} \right)$$

Equation 2-16

Subscripts 1 and 2 define the internal diameters of the small and large pipes respectively.

It is convenient to identify the ratio of diameters of the small to large pipes by the Greek letter  $\beta$  (beta). Using this notation, these equations may be written,

Sudden Enlargement

$$K_1=(1-\beta^2)^2$$

Equation 2-17

Sudden Contraction

$$K_1 = 0.5 \, (1 - \beta^2)$$

Equation 2-18

Equation 2-15 is derived from the momentum equation together with the Bernoulli equation. Equation 2-16 uses the derivation of Equation 2-15 together with the continuity equation and a close approximation of the contraction coefficients determined by Julius Weisbach.<sup>20</sup>

The value of the resistance coefficient in terms of the larger pipe is determined by dividing Equations 2-15 and 2-16 by

$$K_2 = \frac{K_1}{\beta^4}$$

Equation 2-19

The losses due to gradual enlargements in pipes were investigated by A.H. Gibson,  $^{21}$  and may be expressed as a coefficient,  $C_{\bullet}$ , applied to Equation 2-15. Approximate averages of Gibson's coefficients for different included angles of divergence,  $\theta$ , are defined by the equations:

$$C_e = 2.6 \sin \frac{\theta}{2}$$

Equation 2-20

if 
$$45^{\circ} < \theta \le 180^{\circ}$$
  $C_e = 1$ 

Equation 2-21

The losses due to gradual contractions in pipes were established by the analysis of Crane test data, using the same basis as that of Gibson for gradual enlargements, to provide a contraction coefficient, C<sub>o</sub> to be applied to Equation 2.16.

The approximate averages of these coefficients for different included angles of convergence,  $\boldsymbol{\theta},$  are defined by the equations:

if 
$$\theta \le 45^{\circ}$$
  $C_c = 1.6 \sin \frac{\theta}{2}$ 

Equation 2-22

**Equation 2-23** 

$$if \ 45^{\circ} < \theta \le 180^{\circ} \quad C_c = \sqrt{\sin \frac{\theta}{2}}$$

The resistance coefficient K for sudden and gradual enlargements and contractions, expressed in terms of the large pipe, is established by combining equations 2-15 to 2-23 inclusive.

Sudden and Gradual Enlargements

Equation 2-24

if 
$$\theta \le 45^{\circ}$$
  $K_2 = \frac{2.6 \sin \frac{\theta}{2} (1 - \beta^2)^2}{\beta^4}$ 

$$if 45^{\circ} < \theta \le 180^{\circ}$$
  $K_2 = \frac{(1 - \beta^2)^2}{\beta^4}$  Equation 2-25

Sudden and Gradual Contractions

Equation 2-26

if 
$$\theta \le 45^{\circ}$$
  $K_2 = \frac{0.8 \sin \frac{\theta}{2} (1 - \beta^2)}{\beta^4}$ 

Equation 2-27

$$if \ 45^{\circ} < \theta \le 180^{\circ} \quad K_2 = \frac{0.5\sqrt{\sin\frac{\theta}{2}} \ (1 - \beta^2)}{\beta^4}$$

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#### CRANE

#### **Summary of Formulas**

## Panhandle B Equation (fully turbulent flow): Equation 6-14

$$q_h' = 30.708 E \left(\frac{T_b}{P_b'}\right)^{1.02} \left[\frac{(P_1')^2 - (P_2')^2 - \varphi}{L_m T_{avg} Z_{f,avg} S_g^{0.961}}\right]^{0.510} d^{2.53}$$

E is the efficiency factor for the Panhandle A and B equations

E = 1.00 for brand new pipe without any bends, elbows, valves, and change of pipe diameter or elevation
E = 0.95 for very good operating conditions
E = 0.92 for average operating conditions

E = 0.85 for unusually unfavorable operating conditions

AGA Equation (partially turbulent flow): Equation 6-15

$$\frac{1}{\sqrt{f}} = F_f 2 \log \left( \frac{Re\sqrt{f}}{2.825} \right)$$

$$q_h' = 3.2308E\left(\frac{T_b}{P_b'}\right) \left[\frac{(P_1')^2 - (P_2')^2 - \varphi}{L_m T_{ava} Z_{f,ava} S_a}\right]^{0.5} \left[F_f 2 \log\left(\frac{Re\sqrt{f}}{2.825}\right)\right] d^{2.5}$$

The drag factor  $(F_f)$  is used to account for additional resistances such as bends and fittings and ranges in value from 0.90 to 0.99. Specific values may be obtained from the AGA report."

AGA Equation (fully turbulent flow): Equation 6-16

$$\frac{1}{\sqrt{f}} = 2\log\left(\frac{3.7D}{\varepsilon}\right)$$

$$q_h' = 3.2308 \left(\frac{T_b}{P_b'}\right) \left[\frac{(P_1')^2 - (P_2')^2 - \varphi}{L_m T_{avg} Z_{f,avg} S_g}\right]^{0.5} \left[2\log\left(\frac{3.7D}{\varepsilon}\right)\right] d^{2.5}$$

Speed of sound and Mach number: The maximum possible velocity of a compressible fluid in a pipe is equivalent to the speed of sound in the fluid; for a perfect gas this is expressed Equation 6-17

$$v_s = c = \sqrt{kgRT}$$

$$v_s = c = \sqrt{kg144P'\overline{V}} = 68.067\sqrt{kP'\overline{V}}$$

The Mach number is a dimensionless ratio of the velocity of fluid to the speed of sound in fluid at local conditions and is expressed as: Equation 6-18

$$M = \frac{v}{c}$$

Head loss and pressure drop through valves and fittings: Head loss through valves and fittings is generally given in terms of resistance coefficient K which indicates static head loss through a valve in terms of "velocity head" or, equivalent length in pipe diameters L/D that will cause the same head

From Darcy's Formula, head loss through a pipe is: Equation 6-19

$$L = f\left(\frac{L}{D}\right) \frac{v^2}{2g}$$

and head loss through a valve is:  $h_L = K \frac{v^2}{2g}$ Equation 6-20

$$h_L = K \frac{v^2}{2g}$$

Equation 6-21

$$K = f\left(\frac{L}{D}\right)$$

To eliminate needless duplication of formulas, the following are given in terms of K:

Equation 6-22

$$h_L = K \frac{v^2}{2g} = \frac{0.8236 \, KQ^2}{\pi^2 d^4 g} = 0.002593 \frac{KQ^2}{d^4}$$

$$h_L = K \frac{0.0128 \, W^2}{\pi^2 d^4 \rho^2 g} = 4.031 \times 10^{-5} \frac{KW^2}{\rho^2 d^4}$$

$$\Delta P = \frac{\rho}{144} \left( K \frac{v^2}{2g} \right) = \frac{0.005719 \, K \rho Q^2}{\pi^2 d^4 g} = 1.801 \times 10^{-5} \frac{K \rho Q^2}{d^4}$$

$$\Delta P = \frac{8.889 \times 10^{-5} KW^2}{\pi^2 d^4 \rho g} = 2.799 \times 10^{-7} \frac{KW^2}{\rho d^4}$$

For compressible flow with h, or  $\Delta P$  greater than approximately 10% of inlet absolute pressure, the denominator should be multiplied by Y2. For values of Y, see page A-23.

Pressure drop and flow of liquids of low viscosity using flow coefficient: Equation 6-23

$$\Delta P = S \left(\frac{Q}{C_v}\right)^2 = \frac{\rho}{62.364} \left(\frac{Q}{C_v}\right)^2$$

$$Q = C_V \sqrt{\frac{\Delta P}{S}} = 7.897 C_V \sqrt{\frac{\Delta P}{\rho}}$$

$$C_V = Q \sqrt{\frac{S}{\Delta P}} = 0.1266 \ Q \sqrt{\frac{\rho}{\Delta P}} = 29.84 \frac{d^2}{\sqrt{K}}$$

$$K = 890.3 \frac{d^4}{C^2}$$

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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257

### Summary of Formulas

Resistance and Flow coefficients, K and C, in series and Equation 6-24 parallel:

Series:

$$K_{Total} = K_1 + K_2 + K_3 + \cdots K_n$$

$$\frac{1}{C_{v_{Total}}^{2}} = \frac{1}{C_{v_{1}}^{2}} + \frac{1}{C_{v_{2}}^{2}} + \cdots \frac{1}{C_{v_{n}}^{2}}$$

Parallel:

Equation 6-25

$$\frac{1}{\sqrt{K_{Total}}} = \frac{1}{\sqrt{K_1}} + \frac{1}{\sqrt{K_2}} + \frac{1}{\sqrt{K_3}} + \cdots + \frac{1}{\sqrt{K_n}}$$

$$C_{v_{Total}} = C_{v_1} + C_{v_2} + \cdots C_{v_n}$$

Changes in resistance coefficient, K, required to compensate for different pipe I.D.: Equation 6-26

$$K_a = K_b \left(\frac{d_a}{d_b}\right)^4$$

Subscript a refers to the pipe in which the valve will be installed. Subscript b refers to the pipe for which the resistance coefficient K was established.

Representative Resistance Coefficients K for Various Valves and Fittings: The methods and equations for sudden and gradual enlargements and contractions are described on page A-27. The methods for resistance in tees and wyes can be found on page 2-14 to 2-16. Resistance coefficients for valves, elbows, bends, entrances and exits can be found on pages A-28 to A-30.

Discharge of fluid through valves, fittings and pipe; Darcy's formula:

Values of Y are shown on page A-23. For K, Y and  $\Delta P$  determination, see Examples on page 7-13 and 7-14.

Equation 6-27

$$q = 0.04375 d^2 \sqrt{\frac{h_L}{K}} = 0.525 d^2 \sqrt{\frac{\Delta P}{K \rho}}$$

$$Q = 19.64 d^2 \sqrt{\frac{h_L}{K}} = 235.6 d^2 \sqrt{\frac{\Delta P}{K \rho}}$$

$$W = 157.5 \,\rho d^2 \sqrt{\frac{h_L}{K}} = 1890 \,d^2 \sqrt{\frac{\Delta P \rho}{K}}$$

Compressible flow:

Equation 6-28

$$q'_h = 40700 \, Yd^2 \sqrt{\frac{\Delta PP'_1}{KT_1S_g}}$$

$$q'_h = 24700 \frac{Yd^2}{S_g} \sqrt{\frac{\Delta P \rho_1}{K}}$$

$$W = 1890 \, Yd^2 \sqrt{\frac{\Delta P}{K \overline{V_1}}}$$

Flow through orifices, nozzles and venturi:

Values for C can be found from the charts on page A-21 or calculated using  $\mathbf{C_d}$ . Values for  $\mathbf{C_d}$  can be found with the methods outlined on pages 4-5 and 4-6. Values for Y can be found on page A-22 or calculated with the methods on Equation 6-29

$$\beta = \frac{d_1}{d_2}$$

$$C = \frac{C_d}{\sqrt{1 - \beta^4}}$$

Equation 6-30

Equation 6-31

Equation 6-32

CRANE

$$q = CA\sqrt{2gh_L} = CA\sqrt{\frac{2(144)g\Delta P}{\rho}}$$

$$q = 0.04375 \, d_1^2 C \, \sqrt{h_L} = 0.525 \, d_1^2 C \, \sqrt{\frac{\Delta P}{\rho}}$$

$$Q = 19.64 d_1^2 C \sqrt{h_L} = 235.6 d_1^2 C \sqrt{\frac{\Delta P}{\rho}}$$

$$W = 157.5 \, d_1^{\ 2} C \rho \sqrt{h_L} = 1890 \, d_1^{\ 2} C \sqrt{\Delta P \rho}$$

Compressible flow:

$$q = YCA\sqrt{2gh_L} = YCA\sqrt{\frac{2(144)g\Delta P}{\rho}}$$

$$q'_h = 40700 \ Y d_1^2 C \sqrt{\frac{\Delta P P'_1}{T_1 S_g}} = 24700 \ \frac{Y d_1^2 C}{S_g} \sqrt{\Delta P \rho_1}$$

$$W = 1890 \, Y d_1^2 C \sqrt{\Delta P \rho_1}$$

Non-Recoverable Pressure Drop (NRPD): Applicable for ISA1932 and long radius nozzles and Equation 6-33

$$NRPD = \Delta P \left[ \frac{\sqrt{1 - \beta^4 (1 - C_d^2)} - C_d \beta^2}{\sqrt{1 - \beta^4 (1 - C_d^2)} + C_d \beta^2} \right]$$

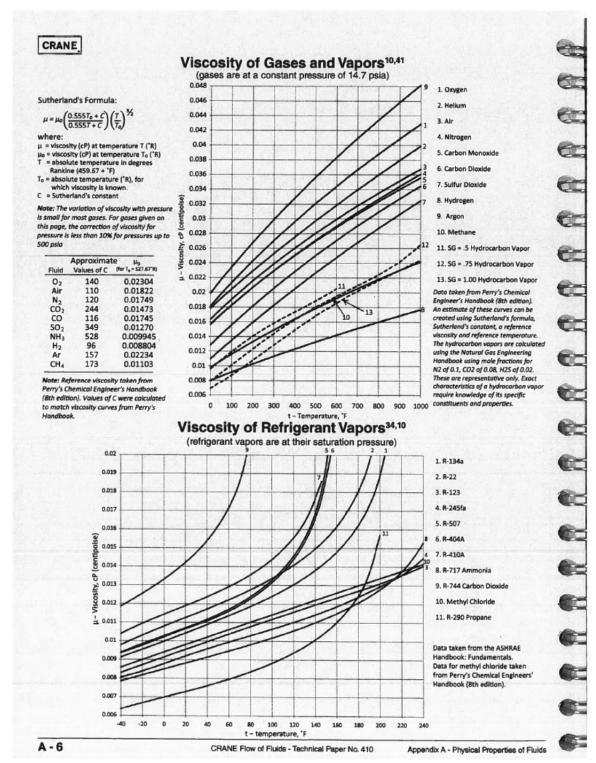
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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257

									CR	AN
		P			rties of (		,37			
	Personal Egypt		Weight	Specific	Individual Gas		Specifi	c Heat	SAD DES	
Name of Gas	Chemical Formula	Molecular Mass M,	Density ρ lb/ft³	Gravity relative to air S <sub>a</sub>	Constant R ft-lb / lb*R	C <sub>p</sub> Btu/(lb °R)	c, Btu/(lb *R)	C <sub>p</sub> Btu/(ft³ °R)	C, Btu/(ft <sup>3</sup> °R)	c,
Acetylene (ethyne)	C,H,	26.080	0.0677	0.900	59.254	0.3987	0.3226	0.0270	0.0218	1.2
Air		28.966	0.0752	1.000	53.350	0.2390	0.1705	0.0180	0.0128	1.4
Ammonia	NH,	17.031	0.0442	0.588	90.737	0.4967	0.3801	0.0220	0.0168	1.3
Argon	Ar	39.948	0.1037	1.379	38.684	1005005		E-90001909		
Butane	C,H,	58.124	0.1509	2.007	26.587	0.3987	0.3645	0.0602	0.0550	1.0
Carbon dioxide	CO,	44.010	0.1142	1.519	35.114	0.2007	0.1556	0.0229	0.0178	1.2
Carbon monoxide	co	28.010	0.0727	0.967	55.171	0.2484	0.1775	0.0181	0.0129	1.4
Chlorine	CI,	70.906	0.1841	2.448	21.794	0.1142	0.0862	0.0210	0.0159	1.3
Ethane	C <sub>2</sub> H <sub>6</sub>	30.069	0.0781	1.038	51.393	0.4112	0.3451	0.0321	0.0269	1.
Ethylene	C <sub>2</sub> H <sub>4</sub>	28.053	0.0728	0.968	55.087	0.3615	0.2907	0.0263	0.0212	1.2
Hellum	He	4.003	0.0104	0.138	386.048		PARTERIAL	THE PROPERTY.	ACTOR MINE	
Hydrogen chloride	HCI	36.461	0.0946	1.259	42.384	0.1909	0.1364	0.0181	0.0129	1.4
Hydrogen	Н,	2.016	0.0052	0.070	766.542	3.4053	2.4203	0.0178	0.0127	1.4
Hydrogen sulphide	H,S	34.076	0.0885	1.176	45.350	0.2392	0.1810	0.0212	0.0160	1.3
Methane	CH,	16.043	0.0416	0.554	96.325	0.5285	0.4047	0.0220	0.0169	1.
Methyl chloride	CH,CI	50.490	0.1311	1.743	30.607	0.1906	0.1513	0.0250	0.0198	1.3
Natural gas	E - E	19.500	0.0506	0.673	79.249	0.5600	0.4410	0.0281	0.0221	1.3
Nitric oxide	NO	30.006	0.0779	1.036	51.501	0.2382	0.1721	0.0186	0.0134	1.3
Nitrogen	N,	28.013	0.0727	0.967	55.165	0.2483	0.1774	0.0181	0.0129	1.4
Nitrous oxide	N,O	44.013	0.1143	1.519	35.111	0.2086	0.1635	0.0238	0.0187	1.3
Oxygen	0,	31.999	0.0831	1.105	48.294	0.2189	0.1568	0.0182	0.0130	1.4
Propane	C,H,	44.097	0.1145	1.522	35.044	0.3923	100000000000000000000000000000000000000		_	-
Propene (propylene)	C,H,	42.081	0.1092	1.453	36.723		-			-
Sulphur dioxide	SO,	64.059	0.1663	2,212	24.124					
Propane Propene (propylene) Sulphur dioxide Molecular mass taken constant are based off deal gas law calculation /alues for isobaric hea he approximate relation	C <sub>2</sub> H <sub>a</sub> C <sub>3</sub> H <sub>b</sub> SO <sub>2</sub> from the Cl of the ideal ons were ba	44.097 42.081 64.059 RC Handboo gas law and used on conductor taken from the conductor of t	0.1145 0.1092 0.1663 k of Chemis the univers litions at 68' m Perry's C	1.522 1.453 2.212 stry and Physics al gas constant F and 14.70 psi	35.044 36.723 24.124 (90th edition). Wigiven in the CRC a.	0.3923 0.3631 0.1481 Veight density: Handbook.	0.3472 0.3159 0.1171 specific gravi	0.0449 0.0397 0.0246 ty relative to	0.0397 0.0345 0.0195 air and indivi	1. 1. 1. dual
	netric	Comp	ositio	n and S		PAVILVE	JI Gase	ous ru	The Part of the Pa	
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Volun		со		Chemical Co	mpositon - Pe	ercent by Vo	olume	0,	G Re	ravit
Type of Gas				Chemical Co	Illum C <sub>2</sub> H <sub>8</sub> (ass C <sub>2</sub>	inates umed <sub>2</sub> H <sub>4</sub> )	olume CO <sub>2</sub>		G Re N <sub>2</sub> to	lati S
Type of Gas		CO 24.1	H <sub>2</sub>	Chemical Co	C <sub>2</sub> H <sub>8</sub> Illum (ass C <sub>2</sub>	inates umed ,H <sub>4</sub> )	Olume CO <sub>2</sub> (4.6 (	0.6 1	G Re to 6.7 0	lation Air S <sub>g</sub>
Type of Gas  Carbureted wate  Coal gas		CO 24.1 5.9	H <sub>2</sub> 32.5 53.2	CH <sub>4</sub> 9.0 29.6	C <sub>2</sub> H <sub>8</sub> (ass C <sub>2</sub> 2.2 10	inates umed (H <sub>4</sub> ) 0.3	DO <sub>2</sub> (4.6 (1.4 (1.4 (1.4 (1.4 (1.4 (1.4 (1.4 (1.4	0.6 1	6.7 0 6.5 0	lation Air S <sub>g</sub>
Type of Gas  Carbureted wate  Coal gas  Natural gas	rgas	CO 24.1 5.9 0.0	H <sub>2</sub> 32.5 53.2 0.0	CH <sub>4</sub> 9.0  29.6  78.8	C <sub>2</sub> H <sub>6</sub> Illum (ass C <sub>2</sub> 2.2 10 0.0 2 14.0 0	inates umed (1) 0.3 2.7 0.00	OO <sub>2</sub> (4.6 (6.1.4 (6.0.	0.6 1	6.7 0 6.5 0 6.8 0	1.65
Type of Gas  Carbureted wate  Coal gas	rgas	CO 24.1 5.9	H <sub>2</sub> 32.5 53.2	CH <sub>4</sub> 9.0 29.6	C <sub>2</sub> H <sub>6</sub> Illum (ass C <sub>2</sub> 2.2 10 0.0 2 14.0 0	inates umed (144) 0.3 2.7 0.0	Dolume  CO <sub>2</sub> 4.6  1.4  0.4  (2.5)	0.6 1 0.7 0 0.0 0	6.7 00 6.5 00 6.8 00 66.0 00	latio Ai

Coke oven gases: 0.339 0.0 1.1 Pittsburgh bed 6.8 56.4 31.1 0.0 3.2 1.3 1.0 0.352 0.0 Elkhorn bed 7.7 55.0 31.0 0.2 4.0 1.1 0.287 1.0 64.8 26.5 0.0 2.5 0.7 0.0 Sewell bed 5.5 1.1 0.4 0.0 0.5 0.222 5.0 75.0 18.0 0.0 Pocahontas no. 4 0.0 1.0 0.391 0.0 2.8 3.8 14.5 56.9 21.0 Illinois, Franklin Co. 1.0 0.416 3.0 0.0 3.7 Utah, Sunnyside 14.5 51.3 26.0 0.5

Specific gravity calculated from percent composition and molecular mass given in "Physical Properties of Gases" table. Compositions taken from Mark's Standard Handbook for Mechanical Engineers (11th edition).

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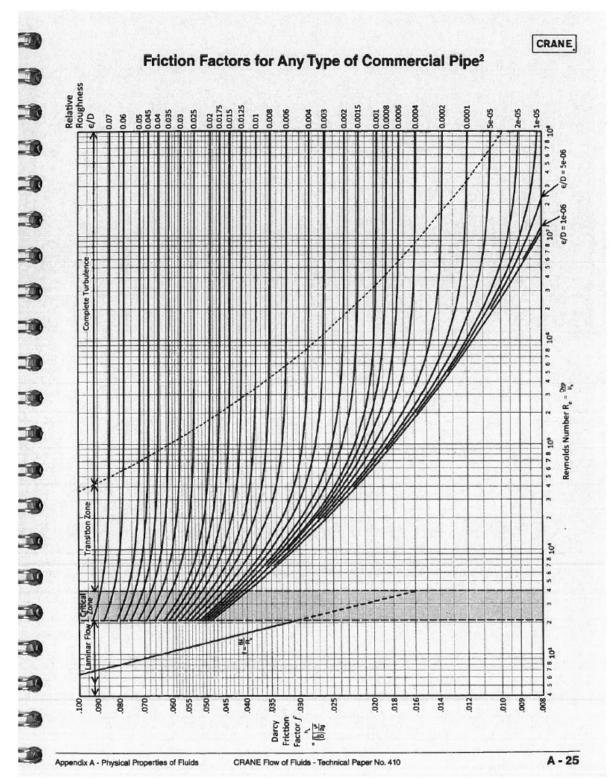
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Factor (f <sub>T</sub> )	.026	.024	.022	.021	.020	.019	.018	.017	.016	.015	.014	.013	.012	.011
						$f_T = -$	$0.25$ $g\left(\frac{\varepsilon/D}{3.7}\right)$	-3					No. L	
							13.7	1						
	For	mulas F	or Cal	culatin	g K Fac	ctors* F	or Valve page 2	es and	Fitting	s with	Reduce	ed Port		
Formula 1						10.01		ula 6						
$K_2 = \frac{0.8  sin}{}$	$n\frac{\theta}{2}(1-$	$\beta^2$ = $\frac{k}{2}$	<u> </u>					$K_2 = \frac{K}{\rho}$	+ For	mula 2	+ Forn	rula 4		
	B	β	,					P						
Formula 2								P	105	σ θ	1 02		2.2	
$K_2 = \frac{0.5\sqrt{s}}{}$	$in\frac{\theta}{2}$ (1 -	$-\beta^2$ )	K <sub>1</sub>					$K_2 = \frac{K_1}{k_2}$	+ 0.5	sin 2	$R^4$	+ (1 - 6	-)-	
N <sub>2</sub> =	β4		β4				Form	ulo 7						
								uia /						
Formula 3														
Formula 3 $K_0 = \frac{2.6  sin}{10^{-3}}$	$n\frac{\theta}{2}(1-$	β <sup>2</sup> ) <sup>2</sup> _	<i>K</i> <sub>1</sub>						β (For	nula 2	+ Form	ula 4)	When t	9 = 18
Formula 3 $K_2 = \frac{2.6  sin}{}$	$\frac{i\frac{\theta}{2}(1-\beta^4)}{\beta^4}$	$\frac{\beta^2)^2}{} =$	$\frac{K_1}{\beta^4}$						β (For	nula 2	+ Form	ula 4)	When (	9 = 18
$K_2 = \frac{2.6  sin}{}$	$\frac{i\frac{\theta}{2}(1-\beta^4)}{\beta^4}$	$\frac{\beta^2)^2}{}=$	$\frac{K_1}{\beta^4}$				K <sub>2</sub>	$=\frac{K_1}{\beta^4}+$					When (	9 = 18
$K_2 = \frac{2.6 \text{ sin}}{}$ Formula 4	,		$\frac{K_1}{\beta^4}$				K <sub>2</sub>	$=\frac{K_1}{\beta^4}+$				ula 4) - β²)²]	When (	9 = 18
$K_2 = \frac{2.6  sin}{}$	,		$\frac{K_1}{\beta^4}$				K <sub>2</sub>	$=\frac{K_1}{\beta^4} + K_2 = \frac{K_1}{\beta^4}$					When t	9 = 18
$K_2 = \frac{2.6 \text{ sin}}{6}$ Formula 4 $K_2 = \frac{(1 - \beta)}{\beta^4}$ Formula 5	$\frac{\beta^2}{\beta^2} = \frac{K}{\beta^2}$	14	p.				K <sub>2</sub>	$=\frac{K_1}{\beta^4}+$					When t	9 = 18
$K_2 = \frac{2.6 \text{ sin}}{}$ Formula 4	$\frac{\beta^2}{\beta^2} = \frac{K}{\beta^2}$	14	p.				K <sub>2</sub>	$= \frac{K_1}{\beta^4} + K_2 = \frac{K_1}{\beta^4}$ $R_3 = \frac{d_1}{d_2}$	+ \beta [0.	5 (1 – µ			When 6	9 = 18
$K_2 = \frac{2.6 \text{ sin}}{6}$ Formula 4 $K_2 = \frac{(1 - \beta)}{\beta^4}$ Formula 5 $K_2 = \frac{K_1}{\beta^4} + F$	$\frac{\beta^2}{\beta^2} = \frac{K}{\beta}$	$\frac{1}{4}$ . $1 + For$	rmula 3				K <sub>2</sub>	$=\frac{K_1}{\beta^4} + K_2 = \frac{K_1}{\beta^4}$	+ \beta [0.	5 (1 – µ			When t	9 = 18
$K_2 = \frac{2.6 \text{ sin}}{6}$ Formula 4 $K_2 = \frac{(1 - \beta)}{\beta^4}$ Formula 5 $K_2 = \frac{K_1}{\beta^4} + F$	$\frac{\beta^2}{\beta^2} = \frac{K}{\beta}$	$\frac{1}{4}$ . $1 + For$	rmula 3		·) <sup>2</sup> ]		K <sub>2</sub>	$= \frac{K_1}{\beta^4} + K_2 = \frac{K_1}{d^2}$ $R = \frac{d_1}{d_2}$ $R^2 = \left(\frac{d}{d}\right)$	$+\beta \left[0\right]$	$\frac{5(1-\mu)}{\beta^4}$	32) + (1	$-\beta^2)^2$		
$K_2 = \frac{2.6 \text{ sin}}{6}$ Formula 4 $K_2 = \frac{(1 - \beta)}{\beta^4}$ Formula 5 $K_2 = \frac{K_1}{\beta^4} + F$ $K_2 = \frac{K_1 + \sin \theta}{\delta^4}$	$\frac{\beta^2}{\beta^2} = \frac{K}{\beta^2}$ Formula $\sin \frac{\theta}{2} [0.8]$	$\frac{1}{4}$ $1 + For$ $\frac{(1 - \beta^2)^2}{\beta^4}$	mula 3 ) + 2.6	$(1-\beta^2)$			K <sub>2</sub>	$= \frac{K_1}{\beta^4} + \frac{K_2}{\beta^4} = \frac{K_1}{d_2}$ $R = \frac{d_1}{d_2}$ $R^2 = \left(\frac{d_1}{d_2}\right)$ where the state of the	$+\beta \left[0\right]$ $\frac{1}{2} = \frac{a}{a}$ define the small	5 (1 - μ β <sup>4</sup>	3 <sup>2</sup> ) + (1		oefficien.	ts with
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$K_2=rac{2.6\ sin}{\kappa_2}$ Formula 4 $K_2=rac{(1-eta)}{eta^4}$ Formula 5 $K_2=rac{K_1}{eta^4}+F$ $K_2=rac{K_1+si}{\kappa_2}$ Use K furnished	$\frac{\beta^2}{\beta^2} = \frac{K}{\beta^2}$ Formula $\sin \frac{\theta}{2} [0.8]$	$\frac{1}{4}$ $1 + For$ $\frac{(1 - \beta^2)^2}{\beta^4}$ e or fitting	rmula 3 ) + 2.6 ng supp	$(1 - \beta^2)$	en avai	lable.	K <sub>2</sub>	$\frac{K_1}{\beta^4} + \frac{K_2}{\beta^4} = \frac{K_1}{d_2}$ $R = \frac{d_1}{d_2}$ $R^2 = \left(\frac{d}{d_2}\right)$ There to the diametric state of	$+\beta \left[0.\frac{1}{a}\right]^2 = \frac{a}{a}$ define the smaler.	$\frac{5(1-\mu)^{\frac{1}{\beta^4}}}{\beta^4}$ s dime	3 <sup>2</sup> ) + (1 a ensions meter.	$-\beta^2)^2$	oefficien ot 2 refer	ts with
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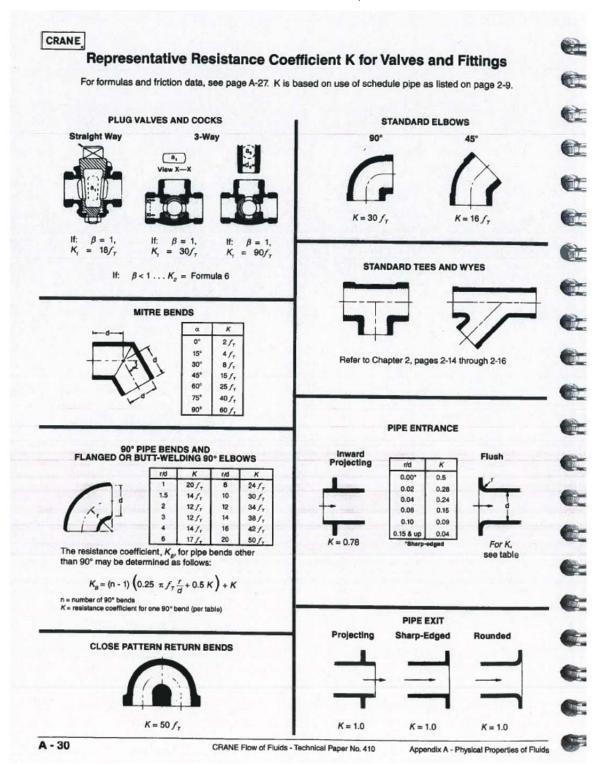


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### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257

### **Equivalents of Absolute (Dynamic) Viscosity**

CRANE

FROM MULTIPLY BY	pascal second Pa·s	poise P	Centipolse cP	pound mass per foot second lbm/(ft-s)	slugs/ft-s or lbf-s/ft²
Pa-s	1	10	1000	0.67197	0.020885
P	0.1	1	100	0.067197	0.0020885
сР	0.001	0.01	1	6.7197E-04	2.08854E-05
Ibm/(ft·s)	1.4882	14.882	1488.2	1	0.031081
slugs/ft·s or lbf·s/ft²	47.88	478.8	47880	32.174	1

To convert absolute or dynamic viscosity from one set of units to another, locate the given set of units in the left hand column and multiply the numerical value by the factor shown horizontally to the right under the set of units desired.

As an example, suppose a given absolute viscosity of 2 poise is to be converted to slugs/foot second. By referring to the table, we find the conversion factor to be 2.0885 (10-3). Then, 2 (poise) times 2.0885 (10-3) = 4.177 (10-3) = 0.004177 slugs/ foot second.

#### **Equivalents of Kinematic Viscosity**

CONVERT TO > FROM MULTIPLY BY	meter squared per second m²/s	stokes St	centistokes cSt	square foot per second ft²/s	square inch per second in²/s
m²/s	1	10000	1E+06	10.764	1550
St	1E-04	1	100	0.0010764	0.155
cSt	1E-06	0.01	1	1.0764E-05	0.00155
ft²/s	0.092903	929.03	92903	1	144
in²/s	6.4516E-04	6.4516	645.16	0.0069444	1

To convert kinematic viscosity from one set of units to another, locate the given set of units in the left hand column and multiply the numerical value by the factor shown horizontally to the right, under the set of units desired.

As an example, suppose a given kinematic viscosity of 0.5 square foot/second is to be converted to centistokes. By referring to the table, we find the conversion factor to be 92,903. Then, 0.5 (sq.ft/sec) times 92,903 = 46,451.5 centistokes.



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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



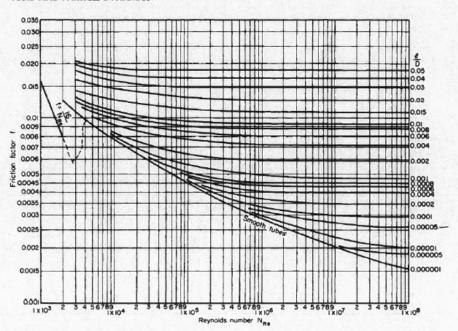


FIG. 6-9 Fanning Friction Factors. Reynolds number Re = DVp/µ, where D = pipe diameter, V = velocity, p = fluid density, and µ = fluid viscosity. (Based on Moody, Trans. ASME, 66, 671 [1944].)

Friction Factor and Reynolds Number 
For a Newtonian fluid in a smooth pipe, dimensional analysis relates the frictional pressure drop per unit length  $\Delta P/L$  to the pipe diameter D, density  $\rho$ , viscosity  $\mu$ , and average velocity V through two dimensionless groups, the Fanning friction factor f and the Reynolds number Re.

$$f = \frac{D\Delta P}{2\rho V^2 L} \tag{6-32}$$

$$Re = \frac{DV\rho}{\mu}$$
 (6-33)

For smooth pipe, the friction factor is a function only of the Reynolds For smooth pipe, the friction factor is a function only of the Reynolds number. In rough pipe, the relative roughness \( \epsilon D \) also affects the friction factor. Figure 6-9 plots \( f \) as a function of Re and \( \epsilon D \) values of \( \epsilon E \) for various materials are given in Table 6-1. The Fanning friction factor should not be confused with the Darcy friction factor used by Moody (Trans. ASME, 66, 671 [1944]), which is four times greater. Using the momentum equation, the stress at the wall of the pipe may be expressed in terms of the friction factor:

$$\tau_w = f \frac{\rho V^2}{2} \qquad (6-34)$$

 $\begin{array}{cccc} \textbf{Laminar} & \textbf{and} & \textbf{Turbulent} & \textbf{Flow} & \textbf{Below a critical Reynolds} \\ \textbf{number} & \textbf{of about 2,100}, & \textbf{the flow is laminar; over the range 2,100} < \textbf{Re} < 5,000 & \textbf{there is a transition to turbulent flow. Reliable correlations} \\ \end{array}$ for the friction factor in transitional flow are not available. For laminar flow, the Hagen-Poiseuille equation

$$f = \frac{16}{\text{Re}}$$
 Re  $\leq 2,100$  (6-35)

TABLE 6-1 Values of Surface Roughness for Various

marerrais	
Material	Surface roughness €, mm
Drawn tubing (brass, lead, glass, and the like)	0.00152
Commercial steel or wrought iron	0.0457
Asphalted cast iron	0.122
Galvanized iron	0.152
Cast iron	0.259
Wood stove	0.183-0.914
Concrete	0.305-3.05
Riveted steel	0.914-9.14

\*From Moody, Trans. Am. Soc. Mech. Eng., 66, 671–684 (1944); Mech. Eng., 69, 1005–1006 (1947). Additional values of ε for various types or conditions of concrete wrought-iron, welded steel, riveted steel, and corrugated-metal pipes are given in Brater and King, Handbook of Hydraulics, 6th ed., McGraw-Hill, New York, 1976, pp. 6-12–6-13. To convert millimeters to feet, multiply by 3.281 x 10<sup>-3</sup>.

may be derived from the Navier-Stokes equation and is in excellent agreement with experimental data. It may be rewritten in terms of volumetric flow rate,  $Q=V\pi D^2/4$ , as

$$Q = \frac{\pi \Delta P D^4}{128 \mu L} \qquad \text{Re} \le 2{,}100 \tag{6-36}$$

For turbulent flow in smooth tubes, the Blasius equation gives the friction factor accurately for a wide range of Reynolds numbers.  $\frac{1}{2} \int_{-\infty}^{\infty} \frac{1}{2} \left( \frac{1}{2} \int_{-\infty}^{\infty} \frac{$ 

$$f = \frac{0.079}{\text{Re}^{0.25}}$$
 4,000 < Re < 10<sup>5</sup> (6-37)

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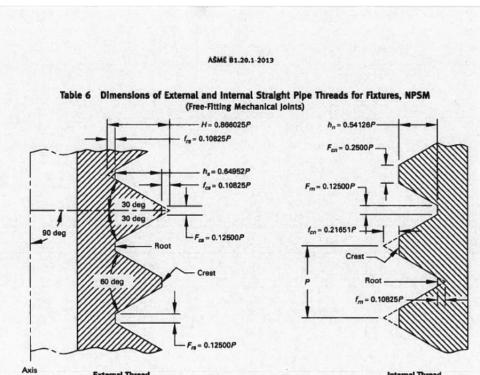
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#### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



		xternal Th	read						Int	ernal Three	id
			140	Ε	xternal Thr	ead, Class 2	'A	100	internal Thr	ead, Class 2	В
Nominal	O.D. of Pipe,	Threads/		Major D	lameter	Pitch D	lameter	Minor E	lameter	Pitch D	iameter
Pipe Size	D	Inch	Allowance	Max.	Min.	Max.	Min.	Min.	Max.	Min.	Max.
1	2	3	4	5	6	7	8	9	10	11	12
1/8	0.405	27	0.0011	0.397	0.390	0.3725	0.3689	0.358	0.364	0.3736	0.3783
1/4	0.540	18	0.0013	0.526	0.517	0.4903	0.4859	0.468	0.481	0.4916	0.4974
3/8	0.675	18	0.0014	0.662	0.653	0.6256	0.6211	0.603	0.612	0.6270	0.6329
1/2	0.840	14	0.0015	0.823	0.813	0.7769	0.7718	0.747	0.759	0.7784	0.7851
3/4	1.050	14	0.0016	1.034	1.024	0.9873	0.9820	0.958	0.970	0.9889	0.9958
1	1.315	11.5	0.0017	1.293	1.281	1.2369	1.2311	1.201	1.211	1.2386	1.2462
11/4	1.660	11.5	0.0018	1.638	1.626	1.5816	1.5756	1.546	1.555	1.5834	1.5912
11/2	1.900	11.5	0.0018	1.877	1.865	1.8205	1.8144	1.785	1.794	1.8223	1.8302
2	2.375	11.5	0.0019	2.351	2.339	2.2944	2.2882	2.259	2.268	2.2963	2.3044
21/2	2.875	8	0.0022	2.841	2.826	2.7600	2.7526	2.708	2.727	2.7622	2.7720
3	3.500	8	0.0023	3.467	3.452	3.3862	3.3786	3.334	3.353	3.3885	3.3984
31/2	4.000	8	0.0023	3.968	3.953	3.8865	3.8788	3.835	3.848	3.8888	3.8988
4	4.500	8	0.0023	4.466	4.451	4.3848	4.3771	4.333	4.346	4.3871	4.3971
5	5.563	8	0.0024	5.528	5.513	5.4469	5.4390	5.395	5.408	5.4493	5.4598
6	6.625	8	0.0024	6.585	6.570	6.5036	6.4955	6.452	6.464	6.5060	6.5165

#### GENERAL NOTES:

- (a) NPSM threads have a form similar to that of UN threads and tolerances similar to 2A/2B. The internal thread has a minimum pitch diameter equal to  $E_1$  of NPT threads.
- (b) The minor diameters of external threads and major diameters of internal threads are those as produced by commercial straight pipe dies and commercial ground straight pipe taps. The major diameter of the external thread has been calculated on the basis of a trunca-tion of 0.10825P, and the minor diameter of the internal thread has been calculated on the basis of a truncation of 0.21651P, to provide no interference at crest and root when product is gaged.

(1) Column 11 is the same as the pitch diameter at the large end of internal thread,  $E_1$ , Basic (see Table 2, column 8).

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### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257

ASME B36.19M-2004

STAINLESS STEEL PIPE

Table 1 Dimensions of Welded and Seamless Stainless Steel Pipe and Nominal Weights of Steel Pipe, Plain End (Cont'd)

	U.S.	Customary Units		Schedule			SI Units	
PS	OD, In.	Wall, in.	Wper lb/ft	No.	DN	OD, mm	Wall, mm	W <sub>per</sub> kg/m
4	4.000	0.083 (1)	3.48	55	90	101.6	2.11 (1)	5.18
1/2	4.000	0.120 (1)	4.98	105	90	101.6	3.05 (1)	7.41
1/	4.000	0.226	9.12	405	90	101.6	5.74	13.57
1/2	4.000	0.318	12.52	805	90	101.6	8.08	18.64
/2	4.000	0.318	12.52	805	90	101.6	8.08	18.04
	4.500	0.083 (1)	3.92	55	100	114.3	2.11 (1)	5.84
	4.500	0.120 (1)	5.62	105	100	114.3	3.05 (1)	8.37
	4.500	0.237	10.80	405	100	114.3	6.02	16.08
	4.500	0.337	15.00	805	100	114.3	8.56	22.32
	5.563	0.109 (1)	6.36	55	125	141.3	2.77 (1)	9.46
	5.563	0.134 (1)	7.78	105	125	141.3	3.40 (1)	11.56
	5.563	0.258	14.63	405	125	141.3	6.55	21.77
	5.563	0.375	20.80	805	125	141.3	9.53	30.97
	6.625	0.109 (1)	7.59	55	150	168.3	2.77 (1)	11.31
	6.625	0.134 (1)	9.30	105	150	168.3	3.40 (1)	13.83
	6.625	0.280	18.99	405	150	168.3	7.11	28.26
	6.625	0.432	28.60	805	150	168.3	10.97	42.56
	8.625	0.109 (1)	9.92	55	200	219.1	2.77 (1)	- 14.78
	8.625	0.148 (1)	13.41	105	200	219.1	3.76 (1)	19.97
	8.625	0.322	28.58	405	200	219.1	8.18	42.55
	8.625	0.500	43.43	805	200	219.1	12.70	64.64
)	10.750	0.134 (1)	15.21	55	250	273.1	3.40 (1)	22.61
0	10.750	0.165 (1)	18.67	105	250	273.1	4.19 (1)	27.79
0	10.750	0.365	40.52	405	250	273.1	9.27	60.31
0	10.750	0.500 (2)	54.79	805	250	273.1	12.70 (2)	81.56
2	12.750	0.156 (1)	21.00	55	300	323.9	3.96 (1)	31.25
2	12.750	0.180 (1)	24.19	105	300	323.9	4.57 (1)	35.99
2	12.750	0.375 (2)	49.61	405	300	323.9	9.53 (2)	73.88
2	12.750	0.500 (2)	65.48	805	300	323.9	12.70 (2)	97.47
4	14.000	0.156 (1)	23.09	55	350	355.6	3.96 (1)	34.34
4	14.000	0.188 (1), (2)	27.76	105	350	355.6	4.78 (1), (2)	41.36
4	14.000	0.375 (2)	54.62	405	350	355.6	9.53 (2)	81.33
4	14.000	0.500 (2)	72.16	805	350	355.6	12.70 (2)	107.40
	16 000	0.165 (4)	27.02		400	1021	440.41	
6	16.000	0.165 (1)	27.93	55	400	406.4	4.19 (1)	41.56
6	16.000	0.188 (1), (2)	31.78	105	400	406.4	4.78 (1), (2)	47.34
6	16.000	0.375 (2)	62.64	405	400	406.4	9.53 (2)	93.27
5	16.000	0.500 (2)	82.85	805	400	406.4	12.70 (2)	123.31
	4-3-14			- September 1		The Arms		yer (d)
8	18.000	0.165 (1)	31.46	55	450	457	4.19 (1)	46.79
8	18.000	0.188 (1), (2)	35.80	105	450	457	4.78 (1), (2)	53.31
8	18.000	0.375 (2)	70.65	405	450	457	9.53 (2)	
8	18.000	0.500 (2)	93.54	805	450	457	12.70 (2)	
		A charges of the					THE RESERVE	
0	20.000	0.188 (1)	39.82	55	500	508	4.78 (1)	59.32
20	20.000	0.218 (1), (2)	46.10	105	500	508	5.54 (1), (2)	68.65
0	20.000	0.375 (2)	78.67	405	500	508	9.53 (2)	117.15
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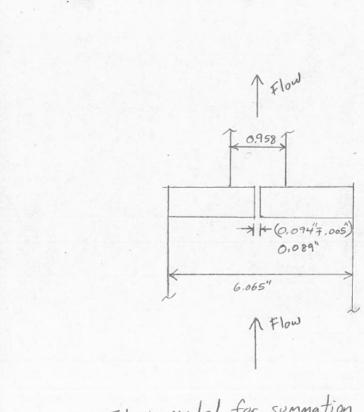
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### Drum POC Lid Vent Flowrate Evaluation, CAL-99-MULT-01257



Flow model for summation of K values

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#### Flowrate testing of the bag filter LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig

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### Flowrate testing of the bag filter LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig

Murray E. Moore Karissa L. Currie Charlotte K. Berg Los Alamos National Laboratory P.O. Box 1663 Los Alamos, NM 87545

#### ABSTRACT

The air flowrate through a flexible HEPA grade filter (Part LANCS-BOP 6CPVC-1.5-2SPVC www.lancsindustries.com) was measured at 48 ALPM for a differential pressure drop of 1.0 psig (28 inWC, 7.0 kPa). These filters are rated by the manufacturer to have a flowrate of 3 ALPM at a differential pressure drop of 1 inWC (0.25 kPa). The Los Alamos National Laboratory Aerosol Engineering Facility used one of their test rigs (originally developed to measure the pressure drop in capsule HEPA filters) to measure the airflow through the LANCS bag filter.



Figure 1. The LANCS-BOP filters are manufactured in standard diameters of 1.5 and 3.5 inches.

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#### Flowrate testing of the bag filter LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig

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#### MATERIALS AND METHODS

The LANL (Los Alamos National Laboratory) AEF (Aerosol Engineering Facility) developed the CFMS (Capsule Filter Measurement System) to measure the pressure drop through capsule HEPA (High Efficiency Particulate Air) filters (Moore and Reeves 2013).

Pressure was measured with a Dwyer manometer (marked at 0.1" divisions). For flow measurements, a TSI model 4045 (SN 1129001) mass flowmeter was used, after its accuracy was checked with a dry gas meter (American Meter AC-250 SN 03D166212). All connections were leak tested according to AEF Leak Test Procedure RP2-RIC-77-R0.



Figure 2. Capsule Filter Measure System (CFMS)

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### Flowrate testing of the bag filter LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig

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Figure 3. Pall Gelman capsule HEPA filter model 12144 (190 mm length).



Figure 4. The LANL FAS (Fixed Air Sampler) filter holder.



Figure 5. The LANCS bag filter was trimmed to 2.125 in (54 mm) diameter for the FAS testing.

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### Flowrate testing of the bag filter LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig

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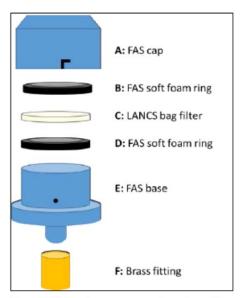


Figure 6. Two O-rings were placed on either side of the filter, since one O-ring allowed leakage.



Figure 7. For the 0.3 µm size channel with ambient aerosol, an optical particle counter measured an 86% bypass leakage with one O-ring in the FAS holder, and 1x10-3% leakage with two O-rings.

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Flowrate testing of the bag filter LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig

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#### RESULTS

The air flowrate through a flexible HEPA grade filter (Part LANCS-BOP 6CPVC-1.5-2SPVC www.lancsindustries.com) was measured at 48 ALPM for a differential pressure drop of 1.0 psig (28 inWC, 7.0 kPa).

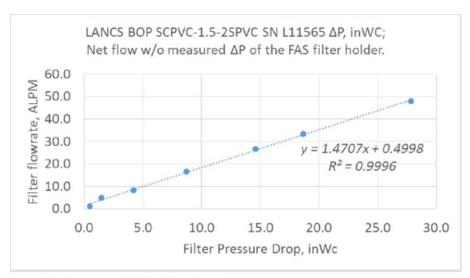


Figure 8. Graphical results of the testing.

Table 1. Tabular results.

LANCS BOP SCPVC-1.5- 2SPVC SN L11565 AP, inWC; Net w/o FAS AP	MetOne flow, Qa, ALPM
0.5	1.0
1.5	4.8
4.2	8.3
8.7	16.5
14.6	26.6
18.7	33.4
27.9	47.8

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#### Flowrate testing of the bag filter LANCS-BOP 6CPVC-1.5-2SPVC (LANCS Industries) at 1 psig

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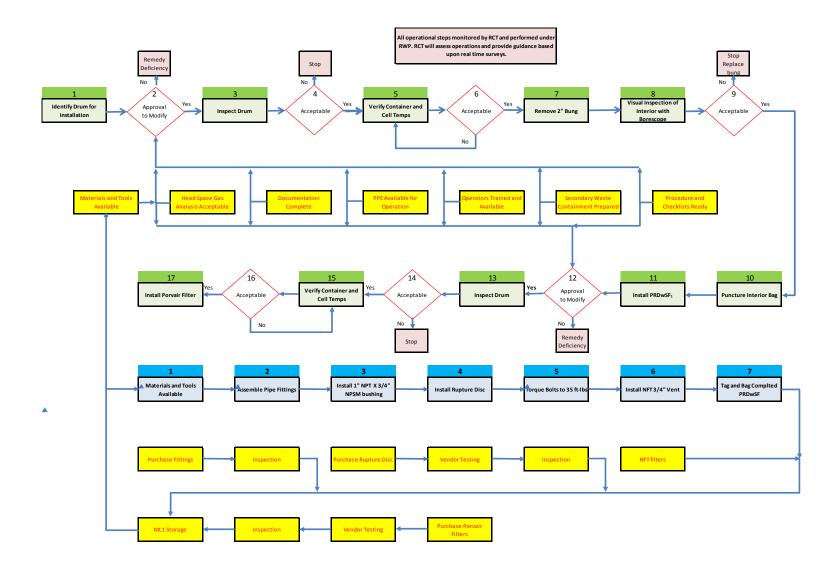
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### Flowchart for PRDwSF Installation in Standard 55-Gallon Drums



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### Flowchart for PRDwSF Installation in POCs

